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THE LOWER RAPIDS OF THE MISSISSIPPI RIVER[1]

In the early days of navigation on the Mississippi two important rapids were found to interrupt the passage of vessels at low-water stages; one, about fifteen miles in length, being above the city of Rock Island, Ill., and the other, about eleven miles in length, above the city of Keokuk, Ia. These became known respectively as the upper and lower rapids. The latter are also called the Des Moines Rapids, because of the situation above the mouth of the Des Moines River. In both rapids the obstructions consist of rock ledges, yet the form or arrangement of the ledges is not the same. The upper rapids consist of a succession of rock barriers called "chains," each usually but a fraction of a mile in breadth, which pass across the river channel and are separated by pools or stretches of slack water. The lower rapids are more uniform, there being a nearly continuous descent across them. The rate of descent, however, varies, as shown below. In opening the upper rapids to navigation it was necessary only to cut channels across the barriers, while in the lower rapids a canal has been constructed. This consists of a channel blasted out of the rock for a distance of three and a half miles from the head of the rapids, below which a retaining embankment is built on the river bed along the Iowa side to the foot of the rapids at Keokuk.

The precise length of the lower rapids is 11.1 miles, the head

[1] Read at Thirteenth Meeting of Iowa Acad. Science at Des Moines, December 28, 1898. Published by permission of the Director of United States Geological Survey.

being at Montrose Island and the foot a short distance above the river bridge at Keokuk. The total descent is 22.17 feet, or very nearly two feet per mile. The rate of descent is greatest in the lower part, there being a fall of about 4¼ feet in the lower mile and nearly eight feet in the lower two miles. From Greenleaf's[1] report on "Water Power of the Mississippi and Tributaries," the following data are obtained. "In the first 4800 feet from the lower lock there is a rise of 4.21 feet, then 2.22 feet in the next 3600 feet, and 1.67 feet in the succeeding 3600 feet to the middle lock, making the fall in ordinary low water from a point opposite the middle lock to the foot of the rapids 8.1 feet." Above this part, the fall, though not uniform, is less definitely broken into rapids and pools than in the upper rapids. Indeed, there appears to be a rock floor forming the river bed throughout the entire length of the lower rapids.

Immediately above the head of the lower rapids a deep preglacial channel appears, whose floor, as shown by several borings, is 125 to 135 feet below the low-water level of the river. This is filled mainly with blue bowlder clay up to about the level of the river bed. Sand, however, in places, extends to a depth of nearly sixty feet below the surface of the river at low water, as shown by the bridge soundings at Ft. Madison and Burlington. A pool extends from the head of the rapids up to the vicinity of Ft. Madison, nine miles. The depth of the pool in places exceeds twenty feet at low-water stage, thus extending to about that distance below the level of the rock surface in the river bed at the head of the rapids.

Below the rapids the river for four miles is in a narrow valley, in which the depth of the drift-filling is not known. It there enters a broad preglacial valley, which has been found to constitute the continuation of that occupied by the river above the rapids, and which no doubt was excavated to a corresponding depth, though as yet no borings have been made which reach its rock floor. The comparative size of the valley of the Mississippi in its new channel across the lower rapids, and the par-

[1] Tenth Census of United States, 1880, Vol. XVII, p. 60.

tially abandoned preglacial valley, is shown in cross-section in Fig. 1, furnished by the Iowa Geological Survey. The depth

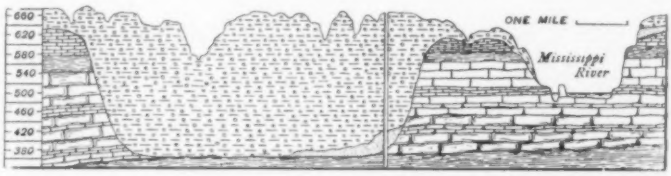

FIG. 1. Cross-section from Sonora, Ill., to Argyle, Ia., showing old and new channels of the Mississippi River (Iowa Geol. Survey).

of the new channel is but little more than half, and the width scarcely one-fifth, that of the preglacial channel. In size it is, therefore, scarcely one-tenth as large as the preglacial valley.

The small size of the Mississippi Valley at the lower rapids, compared with its size above and below, was noted by Worthen more than forty years ago, and interpreted to be an evidence that the greater valley is preglacial, while the portion of the valley across the rapids is postglacial. In the report of Hall, made in 1856, the following statement is found in the discussion of Lee county :[1] "The valley thus scooped out of the solid rocks extends from Montrose to the mouth of Skunk River, and is from six to eight miles in width. The eastern portion of this ancient basin, except the bluffs on the river above Ft. Madison, is now covered by the alluvial deposits before mentioned, while the western part is occupied by deposits of drift material from 100 to 185 feet in thickness. That this valley was formed by ancient currents previous to the drift period is proved by the fact that a considerable portion of it is now occupied by deposits of that age, and which must have been formed after those currents ceased to act." Again, in his first volume of the "Geology of Illinois," published in 1866, Worthen remarks (p. 9) that the present river has shown, by the work done in the upper and lower rapids, how inadequate its erosive power would be to

[1] Geol. of Iowa, Vol. I, 1858, p. 188.

excavate in postglacial time the entire valley, which it now but partially occupies.

A few years later General G. K. Warren discovered the abandoned section of the preglacial valley which crosses Lee county, Iowa, a few miles west of the lower rapids, and connects the portion occupied by the stream above the rapids with that below. In his report in 1878 he presented a discussion illustrated by a map setting forth the position of the old channel.[1] General Warren based his interpretations upon the absence of rock outcrops in the valleys which traverse the old course of the river, there being no borings that extended to the rock bottom. A few years later a boring at Mont Clare, Ia., was sunk in the old valley and brought confirmation to General Warren's interpretation.[2] The accompanying sketch map, Fig. 2, sets forth the position of the old valley and its relation to the one across the rapids.

It should not be inferred that this broad preglacial valley was necessarily a line of discharge for the whole of the present drainage basin of the upper Mississippi. The available evidence concerning the preglacial drainage, though imperfect, is thought to indicate that a large part of the region above the upper rapids may have drained southeastward through the Green River Basin to the Illinois. Hershey has suggested a northward discharge for the headwater portion of the basin, a suggestion which awaits adequate investigation.[3] The preglacial valley which passes the lower rapids on the west is nearly coincident with the present Mississippi from the head of these rapids up to Muscatine, but its position farther north has not been ascertained, nor has the size of its drainage basin been even approximately determined. It is probable, however, that much of eastern Iowa was tributary to this preglacial line.

[1] Report of the U. S. Army Engineers for 1878–9, Vol. IV, Part 2, pp. 916, 917, Diagram E; also Diagram 1, Sheet 4.

[2] Buried River Channels in Southeastern Iowa, by C. H. GORDON, Iowa Geol. Survey, Report for 1893, pp. 239–255, Figs. 5, 6, and 7. Published in 1895 as Vol. III of the present survey.

[3] American Geologist, Vol. XX, 1897, pp. 246–268.

Date of the deflection across the lower rapids.— In previous years attention has been called, both by Mr. Fultz and myself,

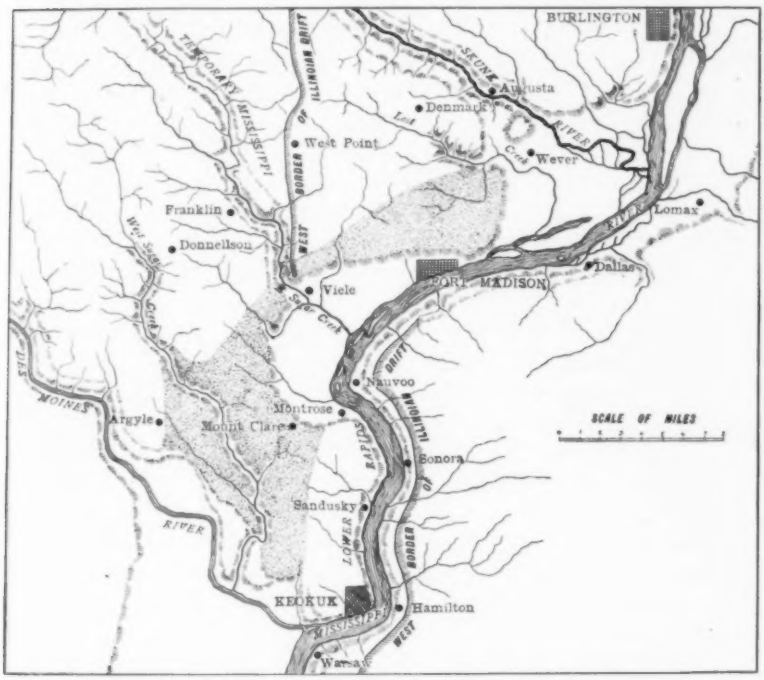

FIG. 2. Sketch map of region discussed, showing course of old channels.

Note of Explanation.— The abandoned portion of the preglacial valley of the Mississippi is shaded. Hachures are used to indicate valley borders both above and below the level of the high terraces, and along the temporary Mississippi channel, opened at the Illinoian stage of glaciation. The extent of the high terrace south of the Des Moines Valley is not determined.

to evidence that the region around the lower rapids presents a complicated glacial history.[1] It has been shown that one ice-field extended southward from Kewatin, in the Dominion of Canada, across Manitoba, Minnesota, and Iowa, into Missouri,

[1] F. M. FULTZ, Proc. Iowa Acad. Sci. for 1895, Vol. II, pp. 209–212; *ibid.*, 1896,

and that it spread eastward beyond the valley of the Mississippi, from near the southern end of the Driftless Area of the upper Mississippi to the vicinity of Hannibal, Missouri. Two invasions may have been made by that ice-field with an intervening deglaciation interval of some length, as indicated by Bain.[1] The later and probably the more extensive advance is referred to the Kansan stage of glaciation. It has also been shown that subsequent to the Kansan stage of glaciation an ice-field extended from Labrador and the heights south of Hudson Bay, southwestward across Michigan, the Lake Michigan Basin, and Illinois into southeastern Iowa.

The Kewatin ice-field not only covered the preglacial valley near the lower rapids, but also the district which the stream traverses in passing the rapids. It was thus liable to have displaced the stream to a much greater extent than the deflection past the rapids, as indicated below. The invasion from Labrador, on the other hand, appears to have barely reached to the rapids and may not have interfered seriously with drainage across them, though it greatly disturbed the course of the Mississippi above the rapids. It did not reach the section of the preglacial valley west of the rapids. The deflection from the preglacial channel must, therefore, be due to the Kewatin ice-field.

But since the Kewatin ice-field may have twice invaded this region it is necessary to inquire into the probable effect of each of its two invasions. If it be found that the earlier invasion extended beyond the line of the preglacial valley and deposited sufficient material to prevent the reëstablishment of the river along the preglacial line, some deflection at this early date must have occurred. The deflection, however, need not necessarily have thrown the stream into its present course across the rapids. That course may have been taken as a result of the later invasion of the Kewatin ice-field, if not as a result of the still later

Vol. III, pp. 60–62; FRANK LEVERETT, Science, January 10, 1896; American Geologist, February 1896; Bull. No. 2, Chi. Acad. Sci., May 1897; Proc. Iowa Acad. Sci., 1897, Vol. V, pp. 71–74.

[1] Proc. Iowa Acad. Sci. for 1897, Vol. V, pp. 86–101.

encroachment of the Labrador ice-field. It is reasonable to suppose that the deflection caused by the Kewatin ice-field might give the stream a course farther to the east than the lower rapids, since the region across which the rapids have been opened appears to have been entirely covered by the Kewatin ice-field at each of its invasions. It will be necessary, therefore, to determine whether the Kewatin field did not establish the Mississippi in a course east of the rapids, and whether that course was not held by the Mississippi until the Labrador ice-field forced it westward into its present course across the lower rapids.

Turning now to the question of the influence of the supposed earlier invasion of the Kewatin ice-field, a few remarks seem necessary concerning the deposits made by that ice-field. The lowest conspicuous member of the drift series in eastern Iowa is a sheet of dark blue till, often nearly black, which is thickly set with fragments of wood and coal. This is overlain by a sheet of blue-gray till, which differs from the blue-black till in texture and rock constituents, as well as in color. It shows a decided tendency to break into rectangular blocks and often presents vertical fissures, extending to a depth of many feet, which are filled with sand and deeply oxidized clay. The blue-black till is very friable and seldom shows a tendency to break into rectangular blocks, while the few fissures which it contains traverse it in oblique rather than vertical lines. The blue-gray till carries much less vegetal material and coal fragments than the blue-black till. It differs also from the blue-black till in containing a larger percentage of greenstone rocks. These differences have naturally led to the suspicion that two quite distinct sheets of till are present, and this suspicion is confirmed by the occasional occurrence of a black soil at the surface of the blue-black till. Such exposures are rare compared with those of the Yarmouth soil, found between the Kansan and Illinoian till sheets,[1] but their rare occurrence may not demonstrate that the interval of deglaciation is of minor importance. From conversations with Calvin, Norton, and Bain, I am led to think that a large part of

[1] See JOUR. GEOL., Vol. VI, 1898, pp. 81–85.

the buried soils, reported by McGee from eastern Iowa,[1] occupy a horizon corresponding to the junction of the blue-gray and blue-black tills of southeastern Iowa. This being true the interval of deglaciation between the blue-gray and blue-black tills becomes of much importance.

The sheet of blue-black till has been found to occur at points farther east than the lower rapids. It occurs in the Mississippi valley in the vicinity of Ft. Madison, Iowa, and in Hancock and Adams counties, Illinois, east and southeast of the rapids. There is little doubt, therefore, that during the deposition of this till the Kewatin ice-field was *sufficiently extensive* to force the Mississippi out of the preglacial channel which passes west of the lower rapids.

It is not certain, however, that the *amount of filling* in that valley was sufficient to prevent the return of the stream to its preglacial course in the interval between the deposition of the blue-black till and the blue-gray till. The blue-black till in the vicinity of Ft. Madison is found to rise to a height of only sixty to seventy-five feet above the present stream, or nearly seventy-five feet less than would probably have been necessary to throw the stream from the preglacial channel into its present course across the rapids. This may possibly have been sufficient to throw the drainage of the portion above the lower rapids eastward into the Illinois, either by way of the Green River basin or by some line farther south, that is now completely concealed by the later sheets of drift. But it seems quite as probable that the stream returned to its preglacial course.

The blue-gray till seems to be fully as extensive a sheet as the underlying blue-black till. It extends eastward into Illinois beneath the Illinoian till sheet an undetermined distance. The tendency to break into rectangular blocks often serves to distinguish it from the overlying Illinoian till, as well as from the underlying blue-black till, though the Illinoian in places takes on this phase of fracture. Probably the most extensive of the

[1] Eleventh Annual Report, U. S. Geol. Surv., 1889–90, pp. 232, 233, 485–496, 541, 569.

exposures of the blue-gray Kansan till are found in the vicinity of Ft. Madison. They there constitute for several miles the upper 100 feet of the Mississippi bluff, except a thin coating of loess.

The filling produced by the blue-gray till was sufficient to prevent the return of the stream to its preglacial course, the altitude of the surface along the part of the preglacial channel west of the lower rapids being as great as in border districts. In this case, therefore, it is only necessary to decide whether the stream assumed its present course across the lower rapids at the time the Kewatin ice-field made its final withdrawal from that region, or whether it drained eastward to the Illinois until it was forced from that course by the advance of the Labrador ice-field, at the Illinoian stage of glaciation. Concerning this question it is thought that evidence of some value has been collected, as appears below.

Erosion preceding the Illinoian stage of glaciation.— The Mississippi valley for about fifty miles below the lower rapids was greatly filled by the drift from the Kewatin ice-field. Immediately below the rapids the filling on the borders of the valley reached a level about 150 feet above the present stream. It seems not improbable that there was a filling to nearly this height in the middle of the valley, for the abandoned section just above was filled in its middle part to as great a height as on its borders. Upon passing down the valley the height of filling gradually decreases to the limits of the Kewatin drift near Hannibal. From the filling of tributaries near Hannibal it is estimated that the Mississippi valley could not have been filled to a height greater than seventy-five feet above the present stream. Below Hannibal the filling was produced by stream action rather than by glacial deposition and appears to have reached but little, if any, above the sand terraces of the valley, say fifty feet above the river. Now if this filling suffered but little erosion before the Illinoian stage of glaciation, it can reasonably be inferred that the drainage of the upper Mississippi did not pass across the lower rapids and through this part of

the valley until forced westward by the advance of the Labrador ice-field. But if a great erosion took place in this part of the valley prior to the Illinoian stage of glaciation there would seem good grounds for supposing that the stream assumed its present course soon after the Kewatin ice-field made its final withdrawal.

Examining into this question it is found that after this drift was deposited by the Kewatin ice-field, an erosion so great took place that it was removed throughout the greater part of the width of the valley down to a level scarcely fifty feet above the present stream at the mouth of the Des Moines, and to an equally low level at Hannibal. The depth of cutting appears, therefore, to have been about 100 feet at the mouth of the Des Moines, and perhaps twenty-five feet at Hannibal. It seems safe to assume an average depth of fifty feet for the entire section and a width of five or six miles, making an erosion of nearly three cubic miles of drift in the fifty miles below the mouth of the Des Moines River. It is scarcely necessary to raise the question whether this erosion could have been accomplished by the Des Moines and other tributaries of the Mississippi below the rapids, for it is evidently out of proportion to the work which these small streams would be able to accomplish since the Kansan stage of glaciation. It seems certain that the Mississippi River is responsible for the principal part of the erosion. This makes necessary the opening of the new channel across the rapids, for the old channel west of the rapids was not utilized by the river after the Kansan stage of glaciation, and no other line of drainage could have been adopted by the river that would pass through the portion of the valley below the rapids.

Evidence is found within the new channel, of an erosion such as the interpretation just given demands. In the south part of Keokuk, between the foot of Main Street and the mouth of Soap Creek the rock bluff rises but fifty to sixty feet above low water, and is capped by a bed of bowlders about twenty feet in depth. Attention was called to this bed some thirty years ago by Mr.

S. J. Wallace, of Keokuk,[1] and the view expressed that it is "old river shingle." Mr. Wallace stated that Dr. George Kellogg, of Keokuk, regarded it as the indication of an old fall at this place, but that he did not so regard it. This bed has been discussed at some length by Dr. C. H. Gordon in the Geology of Iowa,[2] and three interpretations for its origin are presented. (1) That it was formed by river action alone, *i. e.*, as an alluvial bar; (2) that it is due to the cutting down of a till sheet, the coarse material being left as a residue; (3) that it is a bowldery moraine dropped at the edge of the ice sheet at the Illinoian stage of glaciation.

Of the three interpretations the second seems to Mr. Gordon, as well as to the present writer, the most applicable. Dr. Kellogg's suggestion of a fall as the cause seems at least to be poorly sustained. A similar bowlder bed occurs near Warsaw, Ill. It there forms the capping of an eroded till surface and bears clear evidence of removal of the fine material by a stream and the retention of the bowlders as a residue. A bowlder bed is also found along the face of the west bluff of the rapids near Sandusky, about six miles above Keokuk, at a level forty to sixty feet above the stream, that probably was derived from the erosion of a sheet of till. It seems referable to the period of erosion that produced the beds at Keokuk and Warsaw. The exposure, however, is not sufficiently extensive to show clearly its relation to the till sheet.

The amount of erosion effected is so great that the beginning of this new channel seems to date from near the close of the Kansan stage of glaciation. This becomes more evident as we study into the later stages of the history of the river. Even if the river had been forced into a channel farther east than the lower rapids, it seems scarcely probable that it remained long in that course. It apparently began its work of opening the course across the rapids long before the Labrador ice-field had reached the region.

[1] Proc. A. A. A. S., Vol. XVII, 1869, p. 344.

[2] Geology of Iowa, Vol. III, 1893, pp. 252–255.

Filling at the Illinoian stage of glaciation.— Following this great erosion there came a partial filling of the part of the valley immediately outside the limits of the Illinoian drift sheet. It is well displayed below the rapids, and some remnants are to be seen along the borders of the rapids. This filling appears to have occurred at the Illinoian stage of glaciation. Evidence of this relationship is to be found in the connection, or close association, of this filling with the opening of a temporary course for the Mississippi across southeastern Iowa, which occurred at the time the Mississippi valley above the rapids was covered by the Labrador ice-field.

The drainage line referred to leaves the present Mississippi at the mouth of the Maquoketa, passes southward along that valley (reversed) to "Goose Lake channel," and thence to the Wapsipinnicon Valley, connecting with it a few miles above its present mouth. It follows up the Wapsipinnicon a few miles to the mouth of Mud Creek, a southern tributary, which, together with a small tributary of Cedar River, also called Mud Creek, furnishes the line of continuation for the old valley to the Cedar River near the great bend at Moscow. The valley continues southwest to the Iowa River along the course now followed by the Cedar in its lower twenty-five miles. It then passes southward from Columbus Junction to Winfield, and thence westward to Skunk River at Coppock, opening in its westward course two lines, one of which is now utilized by Crooked Creek. From Coppock the old drainage line follows the course of Skunk River southward to Rome, and Cedar Creek (reversed) to Salem. It there turns southeastward, being known as "Grand Valley" in northern Lee county, and joins the Mississippi about six miles west of Fort Madison, nearly opposite the head of the rapids. Its continuation was evidently across the rapids into the broad valley below Keokuk.

The altitude of the bottom of this old valley, near the head of the rapids, is fully 100 feet above the present stream, but connects well with the surface of the valley filling in and below the rapids. It is nearly 100 feet lower than at the point where it

leaves the Iowa valley, 75 miles to the north. The portion above the point where the Iowa is crossed has been so modified since the Illinoian stage of glaciation, that very little is known concerning its condition at the close of that glacial stage, but the portion south from the Iowa valley has been only slightly modified.

Very little material was deposited on the bed of the temporary channel of the Mississippi in the 75 miles from the Iowa valley to the head of the rapids, but a great filling occurred in the broad valley below, and some filling along the rapids, espeally at their lower end. The valley which, at the foot of the rapids, had been cut down to a level scarcely 50 feet above the present stream, was built up to 80 or 90 feet above the river at that point. The depth of filling is found to decrease upon passing down the valley and becomes scarcely noticeable at Hannibal. It is, therefore, much like a delta, formed where a rapid stream emerges into a sluggish lake-like body of water. It consists mainly of fine material, sand or silt, with few pebbles greater than ¼ inch in diameter. A fine gravel, however, appears at an exposure called "Yellow Banks" near the mouth of the Des Moines River. The bowlder bed in Keokuk, described above, received at this time a capping of sand 15 or 20 feet in depth. Sand deposits are also found at a corresponding level in Hamilton, Illinois, near the foot of the rapids, capping a low part of the rock bluff. Another possible remnant of the sand filling is found at Sandusky, Iowa, six miles above Keokuk, immediately back of the bowlder-strewn slope, noted above. It there rises about 80 feet above the river or to within 25 feet of the level of the bottom of the channel of the temporary Mississippi, ten miles to the north. No remnants of the filling have been noted in this interval of 10 miles, and it is thought probable that the rate of fall was so great above Sandusky that but little lodgment of material occurred.

In the portion of the Mississippi valley covered by the Labrador ice-field, at the Illinoian stage of glaciation, there appears to be no such sand filling as is found below the rapids, thus con-

firming strongly the above interpretation, that the sand filling occurred during this stage of glaciation.

In explanation of the small amount of material deposited in the bed of the temporary Mississippi, Professor Chamberlin has suggested to me, that the ground in which this channel was excavated may have been frozen at the time of excavation, its situation being on the immediate borders of the ice-sheet. and that this frozen condition of the ground may have prevented the stream from eroding more material than it could readily transport.

The time involved in the valley filling is a question of much interest, but one on which an estimate is very difficult to make. The filling of any given section is not the measure of the full work of the stream, but simply an index of the excess of material above the limits of transportation by the stream. To properly estimate the work in a stage of filling, it is necessary to compute the amount of material carried through the channel, as well as that deposited in it. It is doubtful if present methods of study are sufficiently refined to enable one to make even an approximate calculation of the time involved. It may safely be affirmed, however, that the filling under discussion progressed slowly, and that the time involved was sufficiently long to affect materially the chronology of the lower rapids.

Erosion conditions during the Sangamon interglacial stage.— Between the Illinoian stage of glaciation and the deposition of loess which accompanied the Iowan stage of glaciation, there was a long interval of time, during which the surface of the Illinoian drift sheet was subjected to leaching and weathering, and the formation of a soil. The name Sangamon has been applied by the present writer to the soil and weathered zone formed at this time, and may properly be made to denote the time interval.[1] Although the degree of weathering and leaching makes it evident that the interval was protracted, the valley excavation appears to have been comparatively slight, so far as depth is

[1] Proc. Iowa Acad. Sci., Vol. V, for 1897, pp. 71–80. Jour. Geol., Vol. VI, 1898, pp. 171–181.

concerned. This is true, not only in the region about the lower rapids, but throughout the entire exposed portion of the Illinoian drift sheet.

The erosion on the lower rapids appears to have been scarcely sufficient to remove the sand filling which occurred during the Illinoian stage of glaciation. It could have amounted to scarcely 20 feet in depth and was mainly in loose material. The limits of the erosion are determined by the level down to which the loess extends. That deposit appears nowhere *in situ* at a lower level than 65 to 70 feet above the head of the rapids. Its lower limits in the portion of the valley above the rapids are also as great as 70 feet above the present stream.

A study of tributary valleys in this region has shown that the streams meandered widely and performed a large amount of work, notwithstanding the shallow depth of erosion. For example, Skunk River, in southeastern Iowa, at that time meandered over a width of about two miles (see Fig. 2), whereas it is now confined to an inner valley scarcely one half mile in average width. It should be noted, however, that the erosion of fifteen or twenty feet, over a width of two miles, by a stream with sluggish current, may involve more time than is required for the cutting of the inner valley, which has an average depth of nearly 100 feet and a width of about one-half mile. In this interval, as in the interval of filling which preceded it, the rapids suffered but little modification, yet the time involved was sufficiently long to affect materially the estimates of the duration of the stream in its present course.

The loess filling accompanying the Iowan stage of glaciation.— The period of low gradient and slack drainage, just discussed, was followed by even less favorable conditions for the opening of a channel. During the Iowan stage of glaciation, as long since pointed out by McGee,[1] and elaborated by Calvin and others,[2] the deposition of a sheet of silt occurred, not only along

[1] The Drainage System and Distribution of the Loess of Eastern Iowa, by W J McGee, Bull. Washington Phil. Soc'y, 1883, Vol. VI, pp. 93–97. Also, see discussion in Eleventh Ann. Rep. U. S. Geol. Surv., 1889–90, pp. 435–471.

[2] Geology of Jones County, by S. Calvin, Iowa Geol. Surv., 1895, Vol. V, pp.

the main valleys, but over much of the low country in the interior of the Mississippi basin. This silt is the problematical loess. Its mode of deposition is still a matter of dispute, the deposit being thought by some glacialists to be largely aqueous, while by others it is thought to be chiefly æolian.

In the region under discussion the valleys, as previously indicated, were opened only to shallow depths, hence only a slight accumulation of the silt was necessary to fill them, or to cause the streams to spread over the bordering plains. The depth of the silt in the vicinity of the lower rapids seldom reaches thirty feet, and probably averages not more than fifteen feet. Its bulk, therefore, does not, so far as the valleys are concerned, greatly exceed that of the filling which occurred below the rapids during the Illinoian stage of glaciation. If, however, the deposits on the bordering plains are taken into consideration, the amount of material deposited is very much greater, for the plains were covered to a depth of six to ten feet by this silt.

Whether the deposition took place by water or by wind, there seems to have been a suspension of erosion on the lower rapids, and the length of this suspension must certainly be sufficient to affect materially their duration. An estimate of the time involved seems at present impossible, there being fewer data for an estimate than in the filling which occurred at the Illinoian stage.

Erosion following the loess filling.—After the deposition of the loess, the valleys throughout much of the Mississippi basin experienced a marked deepening, which brought their bottoms to a lower level than before the loess filling. In the portion of the Mississippi valley, which lies within and near the rapids, the deepening seems to have proceeded continuously to a level nearly as low as the present stream, or fifty to seventy-five feet below the excavation which occurred in the interval following the

63-69. Geology of Johnson County, by S. CALVIN, Iowa Geol. Surv., 1896, Vol. VII, pp. 39-45, 86-89. Geology of Linn County, by W. H. NORTON, Iowa Geol. Surv., 1894, Vol. IV, pp. 168-184. Geology of Marshall County, by S. W. BEYER, Iowa Geol. Surv., 1896, Vol. VII, pp. 234-238. Geology of Plymouth County, by H. F. BAIN, Iowa Geol. Surv., 1897, Vol. VIII, pp. 335-351.

Kansan glaciation. This excavation in the section embraced within the rapids was mainly rock, for the loess and alluvium had built up the channel scarcely thirty feet above the rock floor of the post-Kansan erosion. But for some distance, both above and below these rapids, the excavation was largely in till. The channel across the rapids was opened to a width but little greater than the stream, or about one mile. Elsewhere the channel is three to six times the width of the stream.

This erosion seems to have continued until the early part of the Wisconsin glacial stage, when, as indicated below, another filling occurred. The extent and depth of the erosion which took place prior to the Wisconsin filling is well shown in the broad portion of the valley above the rapids. Numerous wells indicate that the till had been removed nearly to present river level over the greater part of the width of the valley before that filling set in.

The amount of erosion in the Mississippi valley seems to have been nearly as great in this interval as in the post-Kansan interval of erosion. It is doubtful, however, if the time involved was so great as in that interval, for the gradient appears to have been higher. To properly estimate the time involved, it is necessary, also, to know the volume of water discharged through the valley at each interval, a matter concerning which very little is yet known.

Filling at the Wisconsin stage of glaciation.—At the Wisconsin stage of glaciation the Mississippi and several of its tributaries, which flowed away from the ice-sheet, became so burdened by glacial detritus that they were unable to completely transport their load, much less to continue the erosion of their valleys. The Mississippi headed in the ice-sheet near St. Paul, Minnesota, while the Chippewa and Wisconsin rivers brought material from the Chippewa and Green Bay lobes of Wisconsin. Rock River, also, brought material from the Green Bay lobe, and through its tributaries, Kishwaukee and Green rivers, from the Lake Michigan lobe. Just above St. Louis the Illinois River contributed a large amount of material derived from the Lake Michigan lobe.

the main valleys, but over much of the low country in the interior of the Mississippi basin. This silt is the problematical loess. Its mode of deposition is still a matter of dispute, the deposit being thought by some glacialists to be largely aqueous, while by others it is thought to be chiefly æolian.

In the region under discussion the valleys, as previously indicated, were opened only to shallow depths, hence only a slight accumulation of the silt was necessary to fill them, or to cause the streams to spread over the bordering plains. The depth of the silt in the vicinity of the lower rapids seldom reaches thirty feet, and probably averages not more than fifteen feet. Its bulk, therefore, does not, so far as the valleys are concerned, greatly exceed that of the filling which occurred below the rapids during the Illinoian stage of glaciation. If, however, the deposits on the bordering plains are taken into consideration, the amount of material deposited is very much greater, for the plains were covered to a depth of six to ten feet by this silt.

Whether the deposition took place by water or by wind, there seems to have been a suspension of erosion on the lower rapids, and the length of this suspension must certainly be sufficient to affect materially their duration. An estimate of the time involved seems at present impossible, there being fewer data for an estimate than in the filling which occurred at the Illinoian stage.

Erosion following the loess filling.—After the deposition of the loess, the valleys throughout much of the Mississippi basin experienced a marked deepening, which brought their bottoms to a lower level than before the loess filling. In the portion of the Mississippi valley, which lies within and near the rapids, the deepening seems to have proceeded continuously to a level nearly as low as the present stream, or fifty to seventy-five feet below the excavation which occurred in the interval following the

63–69. Geology of Johnson County, by S. CALVIN, Iowa Geol. Surv., 1896, Vol. VII, pp. 39–45, 86–89. Geology of Linn County, by W. H. NORTON, Iowa Geol. Surv., 1894, Vol. IV, pp. 168–184. Geology of Marshall County, by S. W. BEYER, Iowa Geol. Surv., 1896, Vol. VII, pp. 234–238. Geology of Plymouth County, by H. F. BAIN, Iowa Geol. Surv., 1897, Vol. VIII, pp. 335–351.

Kansan glaciation. This excavation in the section embraced within the rapids was mainly rock, for the loess and alluvium had built up the channel scarcely thirty feet above the rock floor of the post-Kansan erosion. But for some distance, both above and below these rapids, the excavation was largely in till. The channel across the rapids was opened to a width but little greater than the stream, or about one mile. Elsewhere the channel is three to six times the width of the stream.

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These streams discharged such large quantities of sand into the Mississippi that the valley was greatly filled as far down as the head of the broad valley of the lower Mississippi at Cairo. Throughout much of the interval between St. Paul and Cairo the valley was filled to a height of fifty to seventy-five feet above the present stream. In the vicinity of the rapids it reached nearly fifty feet above the level of the erosion in the preceding stage of deglaciation.

The filling probably began during the early part of the Wisconsin stage of glaciation, but the great bulk of it appears to have been contributed during the part of the Wisconsin represented by the Kettle morainic system. The transportation of sand down the valley no doubt continued for a long time after the ice-sheet had ceased to contribute material to the headwaters of the present Mississippi. The filling may, therefore, have occupied a longer time than that involved in the formation of all the moraines which cross the headwaters of the Mississippi.

The greater part of this filling consists of sand of medium coarseness. This, however, is interbedded with thin deposits of very fine gravel, and pebbles are also scattered through the sand. The pebbles seldom exceed one half inch in diameter and are usually one fourth inch or less. They have been noted by the writer as far down the valley as the vicinity of Quincy, Illinois. They are a conspicuous feature above Rock Island, Illinois. Upon following up the tributaries of the Mississippi toward the head of these valley trains, the material becomes markedly coarser, as is to be expected on the theory of their derivation from the ice-sheet.

It scarcely needs to be stated that so great a filling has greatly interrupted the removal of the rock barriers of the Mississippi at each of the rapids. A stream with the present volume of the Mississippi and its comparatively low gradient of about six inches per mile, can scarcely do more than remove the material brought in by its tributaries, to say nothing of removing the great amount of material deposited at the Wisconsin stage of glaciation. There appears, however, to have been a long period succeeding

this sand deposition in which the volume of the Mississippi was much greater than at present, and this matter will next receive our attention.

Erosion accomplished by the Lake Agassiz outlet.— Following this period of sand deposition the Mississippi valley afforded a line for the discharge of a large area now tributary to Hudson Bay, an area which was occupied by the glacial Lake Agassiz. The area of this glacial lake and of the country tributary to it is estimated by Upham to have been from 350,000 to 500,000 square miles.[1] This great drainage area has been reduced to about twelve thousand square miles[2] now tributary to the Mississippi through the Minnesota River. The present drainage area of the Mississippi above the lower rapids does not exceed 125,000 square miles, or about one-third the minimum estimate of Upham for the area of Lake Agassiz and its tributaries. Although this great reduction has been in the arid portion of the old drainage basin, it must greatly affect the volume of the river. The present run-off of that region can scarcely furnish a full index, since the ice-sheet was also a great contributor of water to the glacial lake. In addition to the change of drainage area involved in the glacial Lake Agassiz, it is necessary to take into consideration the influx of water from the glacial lake which occupied the western end of the Lake Superior basin, and also a small glacial lake at the head of Green Bay, Wisconsin.

It can scarcely be questioned that at the height of the discharge from Lake Agassiz the volume of water was fully four times that of the present Mississippi. This view is sustained, both by the amount of erosion which took place and by the low gradient reached by the stream. The sand which was deposited as a glacial out-wash while the ice-sheet occupied the head waters of the present Mississippi, was largely removed by the Lake Agassiz outlet, throughout the entire distance from St. Paul to Cairo. It is estimated that the average width of the channel

[1] "The Glacial Lake Agassiz," by WARREN UPHAM, Monograph XXV, U. S. Geol. Survey, 1895, pp. 50–64.

[2] Warren's Report, Bridging Mississippi River, Chief of Engineers U. S. Army, 1878–9, Vol. IV, p. 924.

formed by this outlet is three miles, or about four times the breadth of the present stream.

The depth of erosion seems to have been such as to give portions of the stream a lower level and a lower gradient than that of the present river. This is especially noticeable in the portion above the upper rapids, as indicated by General Warren.[1] Lake Pepin, an expansion of the Mississippi, situated just above the mouth of the Chippewa River has a depth of about sixty feet. It was General Warren's opinion that when the flow of water from the great northern basin ceased, there would no longer be the volume of water necessary to remove the deposits brought in by the Chippewa River. In consequence of this change the Mississippi has been lifted to a level about sixty feet above its former bed. Evidence of a similar filling, produced by the Mississippi at the mouth of the Minnesota, is cited by General Warren. He also noted evidence of the marked shoaling of the Mississippi at the mouth of the Wisconsin. He further expressed the opinion that the entire cutting now in progress on the Mississippi may be confined to short sections in the vicinity of the rapids.

It is of interest to note what a slight change is required to stop the cutting at these places. A filling of only twenty-five feet at the mouth of the Des Moines, or of Rock River, is necessary to cause the neighboring rapids to become protected from erosion. It is not probable, however, that either of these tributaries will for some time, begin the filling of the valley at the foot of the rapids, for the fall of the Mississippi, in passing each of the rapids, is greater than that of the lower course of the Rock, or the Des Moines. Furthermore the main stream has the advantage of much greater volume than these tributaries, in consequence of which the fall across the rapids must be reduced below that of the tributaries before filling can begin at their mouths.

Contours of the bluffs along the lower rapids.—The great length of time involved in the development of a channel across the rapids is shown by the contours of the bluffs. Except at a few

[1] Op. cit., pp. 911–916.

points where the river in rounding a curve has recently encroached upon its bluff there is not an abrupt face. A large part of the slope is so gradual that it has been brought under cultivation. When it is considered that the bluff is composed mainly of a firm limestone, the height of the rock portion ranging from 50 up to 150 feet, with an average height of nearly 100 feet, the prevalence of a moderate slope must indicate a long period of excavation.

But little is yet known concerning the manner in which the rock barrier has been cut away, whether by the recession of a fall, or by the present process of slow cutting across its whole breadth. The fact that the old valley below the rapids was filled with drift about to the height of the highest part of the rock barrier, lends support to the view that there has been a slow cutting down of the entire width of the barrier, rather than the recession of a fall. It seems scarcely probable that the till beneath the stream was scooped out to a much greater degree below the rock barrier, in the early stages of excavation, than at the present day.

Comparison with the upper rapids. — The work performed in cutting away the rock barrier at the lower rapids appears to be several times as great as at the upper rapids. In the latter, the rock excavation has not been sufficient to remove the prominent parts of the barrier. It scarcely amounts to an average cutting ten feet in depth, or one fortieth of a cubic mile. In the rapids under discussion, the barrier is estimated to have suffered a rock excavation to a depth of nearly one hundred feet, or about one fourth of a cubic mile. This difference in amount of work accomplished is readily accounted for by the earlier date at which the lower rapids began excavation. The excavation, as shown above, appears to have been begun soon after the Kansan stage of glaciation, while the excavation at the upper rapids appears to have begun after the Illinoian and to have been mainly accomplished since the Iowan stage of glaciation.

The lower rapids as a chronometer. — When this investigation was entered upon by the writer, hopes were entertained that the

channel across the lower rapids would furnish a valuable chronometer for determining the time since the Kansan stage of glaciation. But from what has been shown, it is evident that the determination of the time is at present very difficult, if not impracticable. It may be thought that this channel will furnish a chronometer for the relative dates of the Kansan, Illinoian, Iowan, and Wisconsin glaciations. But on this question scarcely more than a very rude approximation is likely to be reached. As indicated above, the work involved in filling is very difficult to determine. These difficulties, however, are no greater than those involved in the estimates of the changes of drainage area which the Mississippi has experienced. The object of the present paper is accomplished if the complexity of the history has been adequately presented. The chronological determinations must be deferred to a time when more refined methods of investigation are instituted than are now at command.

FRANK LEVERETT.

THE NEWARK ROCKS OF NEW JERSEY AND NEW YORK[1]

THE Newark rocks extend across the northern part of New Jersey, forming a belt which is about thirty-two miles wide

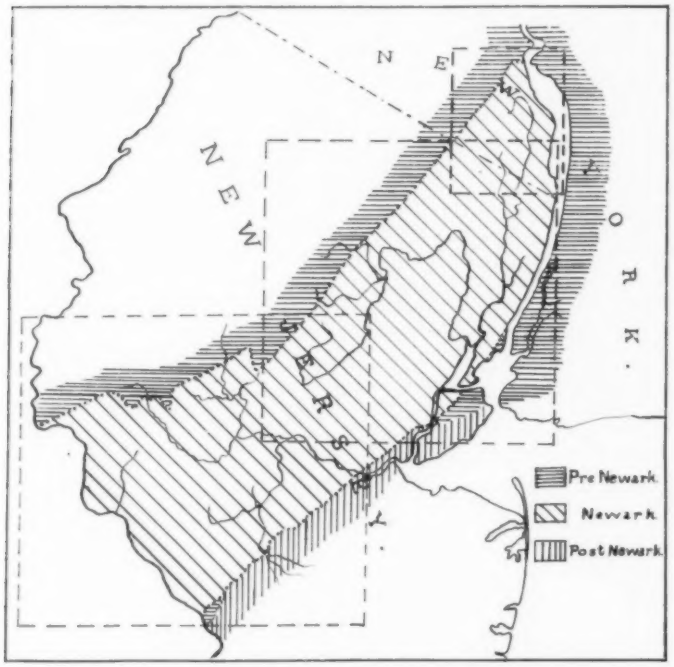

FIG. 1.—Newark area of New Jersey and New York.

along the Delaware River, and fifteen miles wide at the New York state line. In Rockland county, New York, the Newark area forms a right triangle, the apex of which is near Stony

[1] More detailed accounts are given in the following papers: Annual Report of

Point and the hypotenuse along the Hudson River. The southeastern boundary from Trenton northeastward to Staten Island is for the most part formed by overlying beds, Cretaceous and younger. Near Trenton, however, the underlying Philadelphia gneiss outcrops for a few miles. The waters of the Kill von Kull, New York Bay and Hudson River form the boundary from Staten Island northward. The northwestern boundary is irregular and is formed entirely by older rocks — crystallines and Paleozoic shales and limestones. The general position of these rocks and their relations to the older and new formations are shown in Fig. 1.

THE ROCKS

The Newark series consists of sedimentary and igneous rocks. The former are chiefly shales, sandstones and conglomerates; the latter, diabase, to which the more general term trap has usually been applied. Along the Delaware River (Fig. 2) the sedimentary rocks are divisible, on lithological grounds, into three groups, which have been called Stockton, Lockatong, and Brunswick.

Stockton group.— The basal beds of the series are found at Trenton where they rest unconformably upon the older crystalline rocks. They consist of (*a*) coarse, more or less disintegrated arkose conglomerates; (*b*) yellow, micaceous, feldspathic sandstone; (*c*) brown-red sandstones or freestones, and (*d*) soft red argillaceous shales. These are interbedded and many times repeated, a fact which indicates rapidly changing and recurrent conditions of sedimentation. Although there are many layers of red shale in this subdivision the characteristic beds are the arkose conglomerates and sandstones, the latter of which afford valuable building stones.

In addition to the cross-bedded structure which often pre-

the State Geologist of New Jersey for 1896, pp. 25 *et seq.*: Annual Report of the State Geologist of New Jersey for 1897, pp. 23 *et seq.*: JOUR. GEOL., Vol. V, pp. 541–562. A detailed account of the New York area will be published in the Annual Report of the State Geologist of New York, and a briefer summary in the Annual Report of the State Geologist of New Jersey for 1898.

vails in the sandstones, ripple-marks, mud-cracks and impressions of rain-drops occur. The rapid alternation from conglomerates to shales and *vice versa*, the changes in composition in individual beds, the cross-bedding, ripple-marks, etc., all indicate very

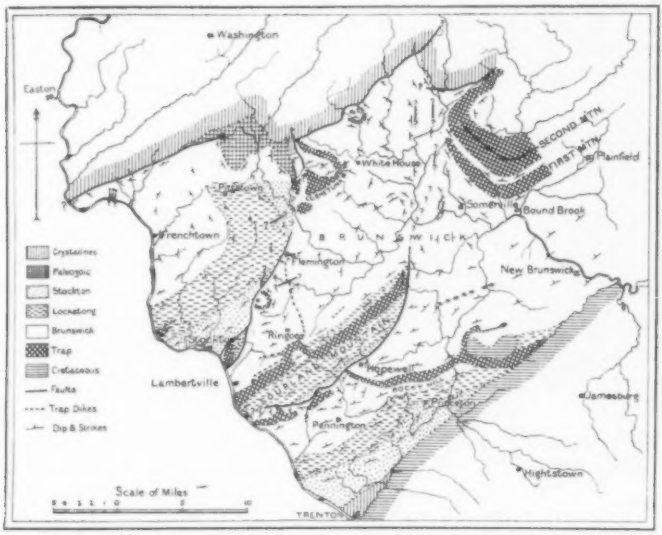

FIG. 2.—Subdivisions of the Newark rocks in Western New Jersey.

clearly that these beds were deposited in shallow water in close proximity to the shore. The bulk of the material of which they are composed was derived from the crystalline rocks on the south and southwest, but where they were found to rest upon Silurian shales, limestones and quartzites, as was the case along the northwestern border north of Flemington, material from these formations has determined their local character. The regions of the Stockton beds form gently rolling lowlands.

The Lockatong group.— These rocks overlie the Stockton beds conformably. They consist of (*a*) carbonaceous shales, which split readily along the bedding planes into thin laminæ, but have no true slaty cleavage; (*b*) hard, massive, black and bluish-

purple argillites; (*c*) dark gray and green flagstones; (*d*) dark red shales approaching a flagstone; (*e*) and occasional thin layers of highly calcareous shales. There are all gradations between these somewhat distinct types, so that the varieties of individual beds are almost countless. Both ripple-marks and mud-cracks occur at all horizons, showing that shallow water conditions prevailed throughout the time of their deposition. On the other hand, the absence of strong currents or violent shore action is indicated by the extreme fineness of the material.

The Lockatong beds are ridge makers, owing to their superior hardness and consequent resistance to the agents of degradation. In this particular they are surpassed only by the trap rocks. Sourland Mountain is composed largely of these rocks, although its backbone is formed by the outcropping edge of a trap sill. The high plateau in Hunterdon county, between Flemington and Frenchtown, which rises 300 to 500 feet above the adjoining region, is due also in large measure to the comparative indestructibility of these hard argillites and flags. They give rise to a rather heavy wet clay soil, often swampy unless artificially drained. The surface is quite thickly strewn with slabs of argillite and flagstone and on the steeper slopes rock outcrops are generally abundant.

The Brunswick beds.— In general this group consists of a monotonous succession of very soft argillaceous red shales which crumble readily to minute fragments, or split into thin flakes. Much of it is porous, the minute, irregular-shaped cavities being often partially filled with a calcareous powder. Calcite veins and crystals are common in some layers. Locally lenticular masses of green shale occur in the red. In size these range up to a foot or two in diameter, and vary in shape from nearly spherical to lenticular masses, narrowing down to thin sheets along cracks. They are undoubtedly due to chemical changes resulting in the leaching of the shale.

Although the majority of this series are soft red shales, there are some hard layers, chiefly near the base, and occasional beds of fine-grained sandstone and flagstones, some of which

afford valuable building material. Massive conglomerates along the northwestern border are in part the shoreward correlatives of the red shales.

Evidence that the shales were deposited in shallow water is abundant. Ripple-marks, mud-cracks and rain-drop impressions occur at many horizons. In some quarries imprints of leaves, of tree stems, or the stems themselves are frequently found. The numerous reptile tracks which have made the Newark beds famous occur chiefly in this subdivision. Typical exposures occur along the Raritan River, particularly near New Brunswick. The Brunswick beds are easily disintegrated and the fineness of the residuary material renders its transportation easy. Consequently the region underlain by these shales forms a lowland of faint relief, much of which has an elevation of only 100 to 200 feet above sea level. This plain is best developed in the drainage basin of the Raritan River, from New Brunswick northwestward to Flemington and White House. These rocks form also the western and lower part of the Hunterdon plateau in the vicinity of Frenchtown.

Owing to two great faults these three subdivisions each occur in three belts in the western part of New Jersey as shown by Fig. 2.

Lithological changes in these types. — Important lithological changes occur in all these beds as they are traced along their strike. As the northwestern border of the formation is approached, near Pittstown, the subdivisions lose their distinctive characteristics and merge along the strike into coarse sandstones and massive conglomerates. This change is most striking in the case of the Brunswick and the Lockatong groups, where red shales or black argillites change to sandstones and then into conglomerates, the pebbles of which are frequently six or eight inches in diameter. Under these conditions it is impossible to differentiate and limit these groups in this part of the field. Before considering these border conglomerates more fully, other modifications in the beds will be noted.

Important changes are found to occur as the beds are traced

along the strike northeastward into New York. The Stockton beds disappear beneath the later deposits a few miles east of Princeton. But owing to a slight change of strike they come to the surface again on both sides of the Palisades from Hoboken

FIG. 3.—Newark rocks of Eastern New Jersey.

northward (Fig. 3). They are exposed in many places along the foot of the Palisades near the water's edge, and in a few localities where the glacial drift is thin, the typical arkose sandstone has been found on the west side of the Palisades. These rocks are correlated with those of the Trenton area for the following reasons. Lithologically, they are almost exactly identical; in both there are coarse arkose sandstones locally con-

glomeratic; in both, red shales and reddish-brown free-stones, and in both, these layers are several times repeated. Second, both occupy the same position stratigraphically. Near Trenton they are found resting upon the older crystalline rocks. In Jersey City wells bored near the water front strike gneiss and schist. At Stevens Point, Hoboken, the crystalline rocks outcrop, and, as is well known, they underlie the whole of Manhattan Island, just across the river. A little over half a mile back from the water front, in Jersey City and Hoboken, wells, which penetrate the glacial drift, reach sandstone and shale, some beds of the former being unmistakably coarse arkose. Third, minute crustaceans (*Estheria ovata*) have been found[1] in the shale beds at Weehawken and Shady Side along the Hudson River, and again in similar relations in the quarries near Trenton. Owing to the intrusion of the Palisade trap sheet some members of the group have been metamorphosed into hard, black and greenish flinty rocks, called hornfels by some German petrographers. Their occurrence, however, is limited to the neighborhood of the trap, and their presence in nowise affects the correlation of these beds with those near Trenton.

The Stockton beds certainly persist into New York, but the typical coarse arkose sandstone beds apparently thin out, and north of Nyack the group cannot be identified with any degree of certainty. The trend of the strata apparently carries the beds of this subdivision beneath the Hudson River.

Northeast of Princeton the outcrop of the typical Lockatong group grows narrower and the thickness less. Either the rate of deposition was slower to the northeast during the time represented by the Lockatong beds elsewhere, and therefore they are thinner here, or else, the rate of deposition being the same as elsewhere, the conditions favoring the deposition of black argillite and shale did not last so long to the northeast of Princeton as nearer the Delaware. A few miles northeast of Princeton the Lockatong beds also are covered by the Cretaceous deposits, but they have been traced by borings as far as

[1] NASON, Annual Report of the State Geologist of New Jersey, 1888, pp. 29–33.

the Raritan River. They do not, however, appear in the region west of the Palisades and north of Newark (Fig. 3). In the region in which they would be expected to occur the broad Newark and Hackensack meadows are found. The Lockatong beds are always ridge makers, rising above the level of the rocks on either side, and therefore it is impossible to suppose that they underlie these great tide-water meadows. There can be no doubt but that the argillites do not exist in the northern region. It is hardly probable that sedimentation ceased entirely in this northern area while the argillites were being deposited in the southwest, since there is no evidence of such oscillations of sea level or of unconformity. It seems more probable that the conditions favoring their formation did not prevail in the northern part of the basin; that here the red shales and sandstones were deposited contemporaneously with the argillites and flagstones to the southwest, and that, could we trace the latter from the point near Princeton, where they disappear beneath the Pensauken and Cretaceous deposits, we would find all the steps in their transition to the soft red shales.

The Brunswick beds likewise change in texture towards the northeast. They are predominantly soft argillaceous shales from the Delaware River as far as Elizabeth. In some layers an increase in coarseness is noticeable, which continues northeastward along the strike, until in the vicinity of Newark and Orange the beds are chiefly sandstones. Many of these beds resemble the brownstones of the Stockton series, so closely in fact that hand specimens can be distinguished with difficulty, if at all, from much of the sandstone at Trenton and Stockton. But their stratigraphical position in the Newark series seems to be far above that of the Stockton beds. The facts on which this conclusion is based are as follows. The trap sheet forming First Mountain is extrusive in origin. That is, it is an overflow sheet,[1] and, therefore, its base is conformable to the

[1] This might not be the case had the lava flowed over an eroded land surface, but evidence will be given below to prove that the lava flow was subaqueous, and therefore contemporaneous with the deposition of the adjoining shales. Its base therefore represents a constant horizon.

bedding of the sandstones, and represents a constant horizon. This being the case it gives us a reliable datum line. The position of the sandstones near Newark and vicinity in reference to the trap agrees with that of the Brunswick *shales* further south, and not with that of the Stockton sandstones. Second, they are too far removed from the base of the series, which follows the Hudson River, to be classed with the Stockton beds. Thirdly, when traced southward along the strike as closely as possible, considering the limited number of outcrops, they appear to grade into soft argillaceous shales.

Still further north layers of conglomerate appear interstratified with the sandstones and shales. In addition to well-marked beds of conglomerate, many layers of the sandstone contain pebbles scattered through them. The pebbles are chiefly of quartzite or sandstone, quartz, slate, limestone, feldspar, and rarely of flint. Not a single gneissic or granitic pebble was found, although careful search was made for them. The coarse sandstone and conglomerates, with some shale beds, continue through Bergen county, N. J., and Rockland county, N. Y. Since this phase of the Brunswick group is more resistant than the argillaceous shales in the Raritan basin, the topography is quite different. Where the Brunswick beds are soft red shales, the surface is a gently-rolling lowland, having an average elevation of from 100 to 200 feet above tide. With the appearance of the coarser and more resistant beds the general elevation becomes greater, and in place of the gently-rolling lowland, we find a series of ridges and valleys following very closely the trend of the beds. Toward the New York state line the higher of these sandstone ridges attain elevations of 450 to 625 feet above tide, the local relief being from 200 to 300 feet.

Owing to the disappearance of the Lockatong beds as a group possessing distinctive features, and the change in the Brunswick group due to the appearance of thick beds of brown sandstone and of coarse conglomerate, it is not practicable to differentiate on a map these groups as sharply as could be done

in the western part of the area. Their general distribution is indicated on the maps shown in Figs. 3 and 4.

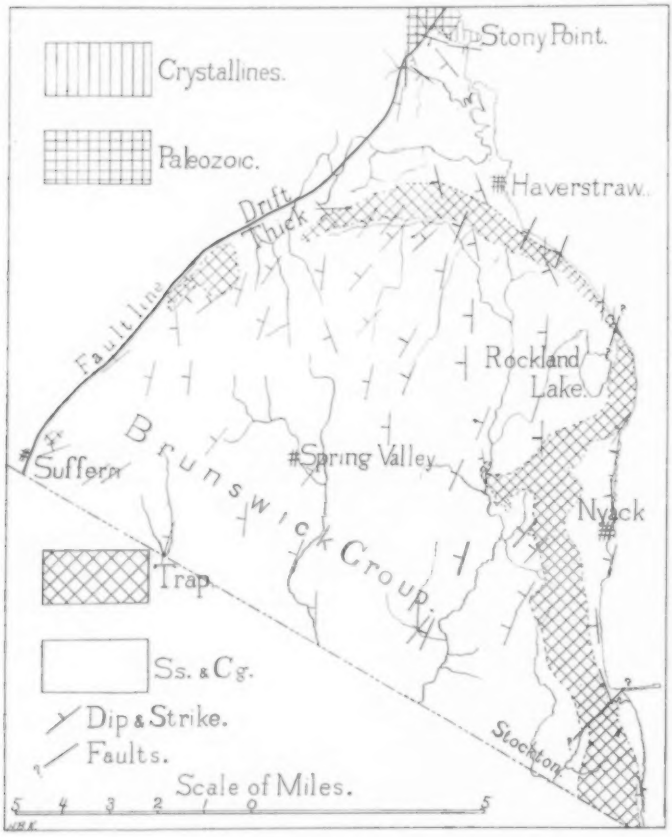

FIG. 4.— Maps of the Newark Series in Rockland County, New York.

Border conglomerates.—Beds of coarse conglomerate occur at a number of points along the northwestern border. Some of these are composed chiefly of quartzite, others of limestone, and in one case of gneissic and granitic material. The quartzite

conglomerate contains a few pebbles of limestone, shale, and gneiss, but almost the entire mass of the rock is made up of quartzite or sandstone pebbles, which are well rounded and frequently six or eight inches in diameter. They are best exposed in the "pebble bluffs" along the Delaware River about five miles above Frenchtown. The conglomerates are interstratified with sandstones and shales, forming lenticular beds, which thin out within a few rods, to be replaced by beds of a different texture. This alternation and rapid change betoken shore conditions. The quartzite conglomerate is also well developed (*a*) in "the Barrens" northwest of Pittstown, (*b*) south of Clinton, (*c*) four miles north of Peapack, where there is an outlier called Mount Paul, (*d*) south of Morristown, and (*e*) south of Pompton Lake.

The calcareous conglomerate is in appearance almost the exact counterpart of the famous "Potomac marble" quarried at Point of Rocks, Maryland.[1] The limestone pebbles are usually bluish or gray, sometimes reddish, set in a red mud matrix, so that the rock has a variegated appearance. The average diameter of the larger constituents is six or eight inches, but bowlders five feet in diameter have been seen, and at a quarry two and a half miles northeast of Suffern, N. Y., bowlders twelve feet in diameter are reported to occur. The larger fragments are generally rounded, but the majority of the smaller are sharp-cornered or at most subangular. Compared with the pebbles in the quartzite conglomerate, the limestone pebbles are but little worn, a fact of some significance in connection with the origin and source of the materials, since with equal transportation the softer limestones must have been most worn. In many localities this conglomerate is so pure a limestone that it is quarried and burnt for lime for local use.

Three small areas of this conglomerate occur northwest of Pittstown between hills of the quartzite conglomerate. A much larger area lies along the border northwest of White House. In New York state it occurs (*a*) two to three miles northeast of Suffern, (*b*) near Ladentown, and (*c*) south of Stony Point.

[1] Geological Survey of Maryland, Vol. II, pp. 187–193.

Not uncommonly the most careful search failed to reveal a single gneissic or granitic pebble in the border conglomerates, even although the adjoining rocks were of this character. But east of Boonton a conglomerate composed chiefly of crystalline pebbles extends for two or three miles along the border.

Relations of these conglomerates to the older rocks.— The relations of these conglomerates to the older rocks along the border are significant. In some cases the calcareous conglomerates adjoin small areas of Paleozoic limestone, from which the materials may have been and probably were derived. In other cases, and *this is true of the largest areas*, the calcareous conglomerates abut against the gneissic rocks, and for much of the distance it is certain that no limestone occurs between the gneiss and conglomerate, at least not at the surface horizon. Crystalline pebbles, however, are comparatively rare in the conglomerate. Substantially the same conditions prevail in the case of the quartzite conglomerate. For the most part it adjoins the gneiss, but gneissic pebbles in it are rare. The known areas of quartzite along the border are small, and in general not near the massive conglomerate beds. Lithologically, moreover, they are unlike the bulk of the quartzite pebbles.

It is evident that along the greater part of this border the beds of the Newark series were not derived from the older rocks which now immediately adjoin them. Shore currents doubtless transported more or less material somewhat widely, and yet they do not afford us the complete explanation for these facts. The northwestern border is for the most part marked by faults. Here the dissimilarity of constitution is the most marked. Where the border is not faulted and the newer rocks rest undisturbed upon the eroded edges of the older beds, they are composed of fragments derived from them plus a small contribution by shore currents. Allowance can be made for the work of the currents, but the widespread dissimilarity of constitution is due chiefly to the faulting which has occurred. The waves of the sea in which the Newark beds were deposited did not on the northwest border in general beat against the rocks which now adjoin this area.

The relation of the conglomerates to the shales is also significant. They do not form a single horizon which may be used in interpreting the structure. Instead, they grade either into argillaceous shales, or black argillites, or arkose sandstones. Time and again the pebbly layers were seen to appear in the shales and to increase in thickness and numbers until they became massive conglomerates. This is true both of the calcareous and quartzite conglomerates, and probably also for the gneiss conglomerate, but owing to the glacial deposits its relation to the shales could not be determined.

The trap rocks.—The trap rocks of the Newark beds in New Jersey and New York have been described more or less in detail by several geologists,[1] and it has been demonstrated that overflow sheets, intrusive sills, plugs, and dikes occur. Owing to its superior hardness, the trap rock has better resisted erosion than the sedimentary beds, and consequently forms more or less well-marked elevations. In the case of narrow dikes, the elevation is slight and readily overlooked, but the greater masses form hills or ridges rising not infrequently 300, 400, or even 500 feet above their surroundings. The structural relations of the trap masses are among the most interesting questions connected with the Newark series, but only general conclusions can be given here.[2] The most important of the overflow sheets are the three concentric ridges forming the Watchung Mountains, Fig. 3. These sheets are to all appearances strictly conformable, both to the underlying and to the overlying shales. Nowhere is there any indication that the trap breaks across the sandstone or shale layers. Wherever the basal contact is exposed, and exposures several hundred feet in extent are known, the trap is seen to follow exactly the bedding plane of the shales.

Moreover, the extensive metamorphism of the associated sedimentary beds, a marked feature in the case of all the intru-

[1] Chiefly Cook, Russell, Davis, Darton, Iddings, Kümmel.

[2] Detailed descriptions are given by N. H. Darton, U. S. Geological Survey, Bulletin No. 67, and by the author in the Annual Report of the State Geologist of New Jersey for 1897, pp. 58–100.

sive sheets, is entirely absent. Locally, the shale is slightly altered for a few inches beneath the trap, but even this is not always the case. When this is compared with the intense alteration which has affected the shales beneath the Palisades, an intrusive sill, for a distance of over 100 feet, the difference between the sheets is emphasized.

Upper contacts have not been observed in many cases, but the upper surface of these sheets is frequently vesicular, amygdaloidal, and scoriaceous. Locally, a thin layer of waterworn trap particles, intermixed with red mud occurs between the vesicular trap and the unaltered typical red shales, or the vesicles are filled with the red mud. The overlying shales conform to the slightly irregular, ropy surface of the trap. In frequent exposures the rolling-flow structure, named by the Hawaiian Islanders *Pa-hoe-hoe*, is visible. Nowhere have any tongues of lava been found extending from the main sheet into the neighboring shales.

In texture there is a marked difference between the overflow sheets and the intrusive sills. Not only is the trap vesicular and even scoriaceous at many points on the upper surface, but it is uniformly of much finer grain than that of the Palisades and similar ridges. Microscopic examination of fragments from the upper surface shows that volcanic glass occurs to some extent. The conclusions drawn from the texture are that these masses cooled much more rapidly than did the Palisade trap. Locally, vesicular and scoriaceous layers occur next to the under-shales, beneath dense, fine-grained trap. Generally in such localities the rolling-flow structure is clearly marked. The inference from these facts is that as the lava flowed onward the partially cooled vesicular slag-like and broken upper surface was rolled over to the under side of the flow, or in other cases, after a clinker-strewn crust had formed on the top and front of the sheet, the molten lava broke forth from within and flowed over and around the scoriaceous fragments, and on hardening bound them firmly together. Occasionally the red shale rises into the base of the trap, as if the great pressure and flowing motion of the molten

lava had forced upward the soft mud on the sea bottom, or as if the steam generated by the intense heat had made the wet mud to froth up between the trap clinkers. There can be no doubt as to the extrusive origin of these sheets.

The crescent-shaped ridges near Morristown, north of White House (near Germantown) and southwest of Flemington (near Sand Brook), are also overflow sheets.

Intrusive sills. — The Palisades of the Hudson, the Rocky Hill sheet north of Princeton, the Sourland Mountain sheet near Lambertville, and Cushetunk Mountain near White House, are the largest and most prominent of the intrusive sheets. Their position, size, and the shape of their outcrop are indicated on the accompanying maps. In addition to these, which are demonstrably sills or sheets, there are more irregularly shaped masses northwest of Pennington, near Stockton, and at Point Pleasant (west of Stockton), (Fig. 2), the precise relations of which to the inclosing beds are not clearly revealed. They are beyond all doubt intrusive masses, but it is questionable whether they are strictly sheets. In the absence of positive knowledge as to their relations with the sedimentary beds, I prefer to speak of them simply as intrusive masses.

The evidence of the intrusive origin of all these masses, sills and others, is as follows. Dikes radiate from the upper part of the sills and penetrate the overlying shales for distances up to seven miles, as measured on the surface. The sills are locally unconformable to the inclosing strata, although in general they extend for long distances parallel to their strike. The Sourland Mountain sill makes two sharp bends, by which it changes its horizon several hundred feet. The Rocky Hill sheet crosses the shales obliquely for a total of several thousand feet, and about twenty-five localities are known along the Hudson River where the Palisade sheet can be seen to cut across the shales and sandstones. In New Jersey the Palisade sheet follows closely the strike of the shales, although frequently changing its horizon a few feet. In New York, however, north of Nyack, the trend of the shales would carry it beneath the Hud-

son River, were it not that it ascends by irregular steps to higher horizons. West of Haverstraw it trends nearly at right angles to the strata, and is more like a dike than an intrusive sheet. A small area near Ladentown, which may be the western extension of the Palisades, presents some characteristics of an overflow sheet, indicating that possibly the trap here reached the surface. The adjacent sediments have often been greatly metamorphosed. So intense has been this alteration that at distances, often of 100 feet the rocks are as completely "baked" as those immediately adjoining the trap. Measured along the surface, traces of metamorphism are frequently found one foot from the nearest trap outcrop. The complete absence of scoriaceous rock, of amygdules, of the vesicular, or the rolling-flow structure, is negative evidence of their intrusive origin which must not be neglected. Moreover, masses of shale and sandstone have been imbedded in the trap near both the under and upper surfaces, and the trap itself shows evidence in its texture of having cooled more slowly (and therefore presumably at greater depths) than the overflow sheets.

Plugs.—Round Mountain, a circular mass of trap, south of Cushetunk Mountain, suggests by its shape, that it is an irruptive plug or stock, but in the absence of positive evidence as to its relations to the surrounding metamorphosed shales, no final statement is warranted.

Dikes.—The positions of the principal dikes are represented on the accompanying maps. A few others are known, but are too small to show on a map of this scale. Locally the adjoining shales are slightly metamorphosed.

The age of the trap rock.—The overflow sheets are contemporaneous with the beds between which they lie, *i. e.*, the upper third of the Brunswick shales.

The intrusive masses extend, for the most part, well up into the Brunswick shales, and are therefore younger than these. Moreover, so far as the evidence goes, they antedate the disturbances which closed the deposition of the Newark beds. There are good reasons for believing that many, perhaps all, of

the intrusive masses are younger than the extrusive sheets, although the evidence is not conclusive. From *a priori* considerations it may be suggested that the lava formed intrusive sheets after the formation became so thick that it could not readily rise to the surface; whereas, earlier in Newark time the lava was able to break through the thinner beds and overflow.

Metamorphosed shales.—The chief effect of the trap on the shales is the contact metamorphism which has been produced by the larger intrusive masses. The most marked macroscopical changes are (*a*) a greater or less induration, (*b*) change in color —red shales in general becoming purple and then a blue-black. streaked with gray or green near the trap, and (*c*) the development of secondary minerals, commonly epidote and tourmaline. The rock often has a banded or mottled appearance, due to the formation of lime-silicate hornfels. Of these three changes the third is the most significant. Mere induration or change of color does not necessarily signify "baking," but when all three occur together, and only in layers in close proximity to certain trap sheets, proved to be intrusive by their structural relations, the changes can be safely ascribed to the igneous rock. Many of the altered shales on weathering become a pale blue or ashy gray color, a tinge never taken by other layers.

Detailed microscopic study of the altered shales has been made by Messrs. Andreæ and Osann[1] from specimens collected at the base of the Palisades at Hoboken and Jersey City. Their results, which were published in Germany, are inaccessible to many readers in this country, and are therefore here briefly summarized. They group the metamorphosed rocks into four classes:

1. Normal slate hornfels, not distinguishable from hornfels formed by contact with intrusives which cooled at great depth.

2. Hornfels containing numerous tourmaline crystals.

[1] Tiefencontact an den intrusiven Diabasen von New Jersey. Separat-abdruck aus den Verhandlungen des Naturhist.-Med. Vereins. zu Heidelberg. *N. T. V.*, Bd. 1. Heft.

3. Metamorphosed arkose sandstone, distinguished by the formation of a fibrous green hornblende.

4. Lime-silicate hornfels (kalksilikat hornfelse).

The two first groups differ only in the presence or absence of tourmaline. They are very dense rocks, with a splinter-like cleavage and abound in biotite. Traces of the original stratification are preserved in the alternation of layers containing varying amounts of mica. The tourmaline always appears as a secondary mineral, in well-bounded black prisms up to three millimeters in length and one in width. They are without definite arrangement, the longitudinal axis being oblique to the stratification plane as frequently as it is parallel to it. Each of the tourmaline crystals is surrounded by a bright halo about half a millimeter in width, caused by the absence of biotite. This may be accounted for on the assumption that the iron and magnesia were consumed in the formation of the tourmaline. The biotite crystals have their tabular planes arranged parallel to the stratification planes.

Feldspar is the chief constituent of the tourmaline-bearing hornfels, and quartz is entirely wanting—a fact which indicates that the original sediment was very deficient in silica, but abounded in clayey materials.

From such rocks, presenting clearly a crystalline structure, a transition may be found to very dense masses in which, even when highly magnified, no constituent parts, save biotite, can be recognized.

The lime-silicate hornfels is bright gray to green-gray in color, dense and hard, and discloses, under the microscope, an irregular aggregate of very small grains, with strong double refraction, whose nature can be determined only from the larger grains. The minerals common to rocks of this variety occur; a colorless pyroxene, closely related to diopside; green hornblende; colorless tremolite in fibrous and radiating aggregates; garnet; vesuvian; epidote; while feldspar occurs commonly in diminished quantity. This rock frequently exhibits an alternation of bright and dark layers, in the former of which diopside usually prevails; in the latter green hornblende and biotite.

Solitary grains and crystals of titanite occur and frequent masses of calcite were observed. The lime-silicate hornfels effervesces with acid. Their occurrence here indicates a deep-seated origin for the Palisade sill.

The association of the slate hornfels and the lime-silicate hornfels is extremely interesting. The former makes up the main mass of the altered beds. The lime-silicate hornfels forms in most cases small layers in the slate hornfels, the thickness of the former often being no greater than that of a sheet of paper. These layers are parallel to each other and to the original stratification of the shales. Frequently they form small elliptical masses, joining each other like a string of pearls in the stratification plane. From this it is but a step to rocks in which the lime-silicate hornfels form only roundish eyes and knots in the hard, black slate, the "incipient segregation," which gives the rock a mottled appearance. In still other cases the lime-silicate hornfels traverses the darker hornfels in veins and bands at various angles to the stratification. Before metamorphism these were probably veins of calcite, which, together with the surrounding shales were altered on the intrusion of the trap.

In all these various relations the boundaries of these two rocks, of such different chemical composition, are sharply marked, both to the naked eye and microscopically. This is strong evidence that during the metamorphism these rocks were not molten, but that the changes occurred in solid, or at most, very slightly plastic beds. The authors conclude that the beds were originally argillaceous shales, locally strongly calcareous and traversed by veins of calcite and interbedded with layers of arkose sandstone. They find in the contact phenomena strong evidence that the trap was intrusive and cooled at great depths.

Metamorphosed shale, in every respect identical with these rocks, so far as macroscopical examination can determine, occurs along the Rocky Hill ridge, and is well shown along the canal near Rocky Hill village. Epidote and tourmaline-bearing shales occur on both sides of the Sourland Mountain trap, and are well exposed at Lambertville, where many of the features

noted by Andreæ and Osann can be seen. Fragments of altered shale can be found on the surface near the other intrusive trap masses, but there are no extensive exposures of the rock in place. Along the Palisade ridge the metamorphism is less pronounced near its northern end in New York, and not infrequently beds in close proximity to the trap here show no signs of alteration. Apparently, as the molten rock approached the surface, its effect upon the adjacent beds was diminished.

STRUCTURE

Folds.— The general structure is that of a faulted monocline the beds of which trend N. 20° to 50° E., and dip 10° to 15° to the northwestward. As a result of this, the layers to the northwest, save where faulting has occurred, are above, and therefore younger than the layers on the southeastern side. When examined more in detail, the structure is seen to depart locally from a monocline. Several broad, gentle flexures occur, in addition to a few sharply marked folds in the vicinity of the intrusive traps and greater fault lines. A good example of the former is seen in the shales of the Hunterdon plateau, where the beds are so inclined that their outcropping edges describe a great curve, parallel on the east, and southeast to the escarpment of the plateau. The structure is a shallow syncline, whose axis is inclined northwestward. Low folds occur in the valley of the Raritan, particularly in the region north of Somerville. From New Brunswick to Bound Brook the dip is quite uniformly to the northwestward, averaging ten degrees, but further to the west the monocline is interrupted by gentle flexures and swells which are difficult to trace because of the absence of individuality in the layers. The broad outcrop of the Brunswick shales in the Raritan valley is due in large part to these low folds.

More definite folds, all synclines, occur (*a*) near the Sand Brook trap sheet, southwest of Flemington, (*b*) the New Germantown trap sheet, and (*c*) the Watchung traps, whose great crescentic curves are due to the synclinal structure of the inclosing shales. Several examples of sharp folds occur near Glen-

more, southwest of Hopewell, and not far from the end of Rocky Hill. Other instances were noted near the faults.

In the area shown in Fig. 2, the Stockton and Lockatong beds are the more constant in dip and strike, so that the monoclinal structure is most marked in these belts. The Brunswick shales are characterized by shallow folds, some of them covering an area of several square miles. These, combined with a fortunate arrangement of faults, have greatly increased the area of red shale outcrop, and so permitted the formation of the broad, rolling lowland, so characteristic of the greater part of the Newark system.

Within the area shown in Fig. 3, the extrusive trap sheets are excellent guides in interpreting the structure, once their conformity to the shales has been completely demonstrated. The curved outline of the Watchung Mountains is due to a gentle synclinal fold, the westward side of which has been cut off by a fault along the highland border of the formation. The highest beds of the Newark series are those along the axis of this syncline. Between the Watchung Mountains and the Hudson River the monoclinal structure prevails. This is also true of the Newark beds of the New York area.

Faults.— About seventy-five faults are known to occur, and two of them, the Flemington and Hopewell faults, are of great magnitude and extent, causing a repetition of all three divisions of the Newark beds and involving dislocations equivalent to a vertical movement of one half the entire thickness of the series, perhaps 6000 or 7000 feet. Faults of such magnitude must extend downward beyond the limits of the Newark rocks, and involve the foundations on which they rest. Proofs of the faulting are found (*a*) in the repetition of the strata, (*b*) crushed and contorted strata, slicken-sided surfaces or overthrown dips at every exposure along or near the fault line, (*c*) diversity of structure on opposite sides of the fractures, (*d*) contrasts in the topography, and (*e*) the termination of ridges at the line of disturbance.

The northwestern border is formed in part by a series of

faults. Elsewhere the Newark beds rest upon the eroded edges of the older rocks. The faulted border is comparatively straight; the normal border is somewhat crooked. Along the former the shales dip in various directions in respect to the older rocks; along the latter they follow the trend of the contact and dip away from the older beds. In the one case Newark beds of very different horizons adjoin the border; in the latter they are basal beds. Along the faulted portion the Newark beds were not derived from the immediately adjoining older rocks; along the normal contact material from the adjacent old formations has entered largely into the newer beds.

The trap ridges, notably the Palisades and the first and second of the Watchung ridges, are cut by a number of faults which cross them obliquely. Second Mountain, moreover, is cut by a curving fault which follows the ridge for many miles, producing a double crest and revealing a strip of shale in the valley between. The throws of the faults rarely exceed 200 feet, save in the case of this longitudinal fracture where it is probably 700 feet or over. Owing to the monotonously uniform character of so many of the sedimentary beds, all estimates of the amount of throw are generally unreliable. Faulting is more frequent in the Brunswick and Stockton beds than in the Lockatong group, but the total number observed in all three subdivisions is hardly more than that found in the trap areas. There is good reason for believing that many faults which traverse the sedimentary beds have not been discovered, and perhaps never will be, with the present methods of geological research. With but few exceptions, all the known faults are reverse faults.

The thickness of the sedimentary beds.—In my earlier papers the following estimate of the maximum thickness of these beds was made.

Stockton, - - - - -	4,700 feet.
Lockatong, - - - - -	3,600 "
Brunswick, - - - - -	12,000 "
	20,300 "

At that time it was felt that not all these estimates were

equally reliable. Six sections were made across the Lockatong beds with the following results: Across the belt on the Hunterdon plateau, 3540 feet, 3450 feet, 3500 feet; across the Sourland Mountain area, 3600 feet, 3650, 3660 feet. The sweeping curve of this belt in the Hunterdon area, its uniform width, and the possibility of tracing certain subordinate but well-marked layers continuously along the strike preclude the idea that any great part of its apparent thickness is due to repetition by faulting. Furthermore, the fact that the beds on the Sourland plateau agree in thickness so closely with the same beds on the Hunterdon plateau is further reason for believing that the figures here given represent very closely the actual thickness. To suppose otherwise is to assume that these two separate areas are each traversed by faults, whose throw, by a remarkable coincidence, is almost exactly the same, but of which no traces have been discovered by areal work of the most detailed character.

The thickness of the Lockatong beds, near Ewingville and Princeton, seems to be only half of that in the other two regions, *i. e.*, 1700 to 1800 feet. The same relative thinness was observed in the Stockton beds, near Trenton, as compared with those further north. The explanation of this may lie in the fact that the beds of the former belt are nearer the old shore line than the others. Stratified deposits have the form of an unsymmetrical lens which thins out very rapidly shoreward and very gradually seaward. It is to be expected, therefore, that the thickness of this belt, which is nearest the old shore, would be somewhat less than that of the others. The weight of evidence indicates that in the deeper parts of the estuary the Lockatong beds were 3500 or 3600 feet thick.

The estimates for the Stockton and Brunswick beds are more uncertain. In favor of the estimates given above these facts may be urged. West of Ringoes the Brunswick shales form a syncline whose axis plunges northwest. Between 6000 and 7000 feet of shales are involved in this fold. It is improbable that a fault could follow the curving strike so as to repeat the

beds the same amount on both sides of the fold. Furthermore, a narrow trap dike was traced uninterruptedly from the back of Sourland Mountain, near Rocktown, to Copper Hill, a distance of five miles. The dike crosses the strike at an angle of forty-five degrees, and the thickness of the shales thus traversed is between 6000 and 7000 feet. There are reasons for believing that the trap was intruded before the tilting and faulting. If these reasons are valid the continuity of the dike is proof that the shales traversed by it are not cut by faults along the strike Since such great thicknesses prevail in these beds, which are only a part of the whole, there is some reason for believing that the entire thickness of the Brunswick shales is near 12,000 feet.

On the other hand the disparity in the number of known faults in the trap areas and in the sandstone and shale areas indicates that there are probably more faults in the sedimentary beds than have been discovered. The apparent thickness of the Palisades and the two Watchung ridges is from one half to one third greater than the actual thickness, the increase being due to the faults. If the same proportions hold for the Stockton and Brunswick shales the figures given above will be somewhat reduced. The revised estimate, therefore, is as follows:

Stockton, - - -	2,300 to	3,100 feet.
Lockatong, - - -	3,500 "	3,600 "
Brunswick, - - -	6,000 "	8,000 "
	11,800 "	14,700 "

There is so much uncertainty connected with all measurements where there are so many unknown elements that these estimates may be far from correct. It certainly can be claimed for them, however, that they rest upon a much larger basis of fact than many previous figures.

Of the trap sheets.—The thicknesses of the various trap sheets are not included in the above estimates.

The Palisades at Jersey City Heights have at least a thickness of 364 feet (well-boring), with a total thickness, including the amount removed by erosion, of 700 to 800 feet, according

to estimates made from the angle of dip and the width of outcrop. At Fort Lee a well penetrated the trap for 875 feet before reaching the underlying metamorphosed shale and the total thickness here is about 950 feet.

In New York the thickness varies considerably, judging by the width of outcrop. A thickness of considerably over 700 feet is known to occur north of Nyack, whereas north of Rockland Lake it probably does not exceed 300 feet.

The thickness of First Mountain at Paterson is estimated to be 600 to 675 feet; at Orange Valley about 670 feet; at Scotch Plains about 680 feet, and at Chimney Rock about 580 feet.

With the exception of the thickness at Scotch Plains these figures agree closely with those obtained for First Mountain by Darton along the same sections. At Scotch Plains the outcrop is narrower than elsewhere, but the dip of the inclosing shales is steeper and his estimate of 450 feet is probably too low.

The thickness of Second Mountain is apparently somewhat greater than that of First Mountain, but owing to the faults which traverse it, estimates are liable to error. Darton's figures range from 600 to 850 feet. My own estimates, based on the width of outcrop and the dip, range from 840 feet to 990 feet. At Caldwell the well at the Mount St. Dominic Academy penetrated the trap for nearly 800 feet, but some addition must be made for what has been removed from the crest of the ridge by erosion.

At Millington the thickness of the Long Hill trap sheet is about 300 feet. At Pompton a well drilled at the Norton house is reported to have passed through but seventy feet of trap before reaching sandstone. Hook Mountain, east of White Hall, has an apparent thickness of 400 feet or more.

The New Vernon trap-sheet has a thickness of about 250 feet, measured at the gorge near Green Village.

The outcrop of the New Germantown sheet is comparatively narrow, but the dip is steep and the thickness is estimated to be at least 400 feet.

The same thing is true of the Sand Brook sheet, the thickness of which is apparently not less than 425 feet.

Too little is known of the relations of the Sourland Mountain, Pennington Mountain, Bald Pate, and Rocky Hill traps to the inclosing shales to venture estimates of their thickness.

Deposition.— Most geologists hold the view that the Newark beds are estuarine deposits. Some, however, prefer to consider them lacustrine, believing that the scarcity of fossil remains renders improbable the supposition that the sea had free access to the basin. The fauna and flora preserved for us are meager, and do not settle the question decisively, the forms being such as might have existed either in an estuary or a salt lake. On the other hand, the distribution of the material implies well-marked currents such as the tides would produce in an estuary. For myself I prefer to believe that at the beginning of Newark time a broad, shallow estuary extended across the northern part of what is now New Jersey and into New York state. Whether the estuary was wider than the present area of the beds is impossible to say. Subsequent erosion has diminished their areal extent, whereas faulting, particularly in the western part of New Jersey, has increased it. Which of these factors has been the more effective is uncertain. Probably along the Delaware River section the gain by faulting has exceeded the loss in width by erosion. In the north this may not be the case.

The estuary was bordered on the northwest and southeast by areas of granite, gneiss, and schist, probably pre-Cambrian in age, with narrow belts of Paleozoic quartzite, limestone, and shale. The latter rocks formed in part the floor of the estuary, the foundation on which the Newark deposits were made. This is shown by the "island" of limestone and quartzite brought to the surface in Pennsylvania by the Flemington fault. For long periods previous to the formation of the estuary and the deposition of the Newark shales, the older rocks on which they now rest had been a land area and were deeply eroded. The proof of this is found in the absence from this region of all the later members of the Paleozoic series.

The constitution of the arkose sandstones near Trenton and beneath the Palisades shows that the sediment was derived chiefly from older crystallines on the southeast, but scattered limestone and sandstones pebbles derived from the southwest show that the currents had a northward trend along the southeastern border. Along the northwestern border, where it is not marked by faults, the material was evidently derived from the adjacent rocks on the northwest.

The constitution of the Newark beds points to the conclusion that in pre-Newark times the old land surface was deeply covered with residuary material, the product of long-continued subaërial decomposition. On the crystalline areas it was chiefly quartz and feldspar or kaolin. The limestone was buried beneath a mantle of clay. In both cases the residuary products had been formed chiefly by chemical agencies. The sandstone and quartzite rocks were less affected by chemical changes and relatively more by mechanical agencies. Their surface was, therefore, covered by subangular fragments, due chiefly to the rending action of frost and expansion and contraction with changes of temperature. The almost complete absence of gneissic pebbles with the presence of quartz, feldspar and partially disintegrated ferro-magnesian minerals in the conglomerates, sandstone or shales proves that the crystalline rocks must have been deeply covered with a mantle of residuary material, so that streams, although they had velocity enough to carry pebbles two or three inches in diameter, did not corrade the bed rock, but worked in the residuary material.

The bulk of the Newark beds is so great as to indicate that these residuary products must have been very thick. Their accumulation was aided by gentle slopes, hindered by steep declivities. Previous to the formation of the Newark beds the neighboring land surface seems to have been one of low relief, with gentle slopes, across which transportation was reduced to a minimum. In other words, the land surface was approaching the peneplain stage.[1] Had the land been high and the slopes

[1] Practically the same conclusion has been reached by Professor Davis in regard

steep the accumulation of these residuary materials in a thick mantle would seem to have been improbable. But the size of the materials handled by the streams during the Newark time indicates a velocity inconsistent with streams on a peneplain. It would seem, therefore, that with the beginning of the Newark deposition the land regained something of its former elevation. The rivers were able to carry from the crystalline areas pebbles of quartz or feldspar several inches in diameter and to handle quartzite cobbles ranging up to a foot in size.

The massive border conglomerates are probably not composed entirely of stream-transported material. Limestone bowlders poorly rounded and measuring four feet in diameter have been seen, and some twelve feet in diameter are reported to occur in the calcareous conglomerates. All the coarser border conglomerates were probably accumulated by the waves which beat against limestone and quartzite ledges. The scarcity of gneissic conglomerates indicates that the shores were not chiefly gneissic, as would be the case today were the Newark area to be submerged, but of limestone and quartzite. The faults along the northwest border have, for the most part, cut out these rocks, and brought the Newark beds against the crystallines.

That the sandstones and shales were accumulated in shallow water, is shown by the ripple marks, mud cracks, raindrop imprints, and footprints of reptiles and other vertebrates, which occur at all horizons. At no time apparently was the water of the estuary so deep that the outgoing tide did not expose broad areas of sand or mud. It follows from this that there must have been a progressive subsidence of the estuary during the deposition of these beds, since their thickness is to be measured by thousands of feet. The subsidence went on *pari passu* with the deposition of the sediments, since the shallow-water conditions prevailed continually. The progressive elevation of the adjoining land areas, shown by the material carried by the rivers, was

to the surface on which the Newark beds in Connecticut were deposited. His argument, however, was along an entirely different line of reasoning, being based upon the present topography.

complementary to this subsidence of the trough. If the subsidence were greater along one side of the trough than the other, the central axis must have shifted toward the side of greater depression, and the shore line on that side must have encroached upon the land. If this occurred to any marked degree during the later stages of sedimentation, the shore conglomerates of that time might rest upon the older rocks and so be basal conglomerates. At the same time they would be the correlatives of the topmost shales found further from shore. In this sense they would be the upper members of the series. This may have been the case locally along the northwestern border, and at the northern end of the estuary near Stony Point, but the evidence is far from conclusive on that point.

The lava flows.— Before the completion of the Newark sedimentation the quiet course of deposition was interrupted by great flows of lava. Whether the lava issued from a single vent or group of vents, or from a fissure is unknown. Certain it is, however, that the molten lava flowed over the soft mud in the bottom of the estuary. Locally the mud was forced up into cracks in the under side of the lava, or was thrown into low billows by the enormous pressure of the overflowing mass. The molten rock issuing forth into the water generated an enormous amount of steam, causing the mud to froth up and mingle with the scoriaceous lava. So, too, the more liquid lava flowed around and over the cooled and broken masses of clinkers, forming the ropy structure and the commingling of dense trap and breccia-like scoriæ sometimes seen in the Watchung trap sheets. Locally, perhaps somewhat generally, the lava flows were so thick as to rise above the sea level. In these cases the scoriaceous surface was readily eroded: the waterworn trap fragments were commingled with the red mud brought into the estuary by the rivers, and a layer of trap conglomerate or sandstone was formed. Such was the origin of the conglomerate in the back of the first Watchung sheet near Feltville. In other localities the vesicles on the upper surface of the lava were filled with the red mud as the lava flow was buried beneath the succeeding sediments. The three

Watchung trap sheets give us evidence of at least three periods of eruption separated by long intervals of quiet, during which the deposition of the shales went on as regularly as before. The intrusive sheets were probably formed after the overflow sheets but this has not been conclusively demonstrated. Since both the intrusive masses (save perhaps some dikes) and the extrusive sheets are cut by the faults, the volcanic phenomena preceded the faulting.

Professor Davis[1] has suggested that the disturbing force which ended the deposition, was probably "a long enduring and slow acting horizontal compression, exerted in an east and west, or southeast and northwest direction; and that the explanation of the tilted and faulted structure is to be found in the writhing and rising of the inclined layers of underlying gneiss and schist, as they were subjected to this horizontal compression." The foundation on which the Newark sediments rest would thus be faulted and canted, and "the overlying beds, unable to support themselves unbroken on this uneven foundation, settle down upon it as best they may." This explanation, offered to meet the conditions of the Newark beds of Connecticut, is fully applicable in its general features to the New York and New Jersey area.

HENRY B. KÜMMEL.

LEWIS INSTITUTE,
Chicago, January 1, 1899.

[1] DAVIS, U. S. Geological Survey. Seventh Annual Report, pp. 481–490.

THE PETROGRAPHICAL PROVINCE OF ESSEX COUNTY, MASS. II

Essexite.—The term essexite was first introduced by Sears who applied it to a group of basic rocks composed essentially of augite, hornblende, biotite, and plagioclase, with subordinate orthoclase, nepheline. or sodalite, which he regarded as the earliest crystallized and most basic portion of the nepheline-syenite magma of Salem Neck.[1] Rosenbusch[2] enlarges the mineral list to include olivine and apatite, and erects the essexite into a group of igneous rocks of the same order as the granites or diorites. He says of them that they are related to the gabbro family as the monzonites are to the normal syenites. They may therefore be considered as essentially basic monzonitic rocks, in which both lime-soda and alkali-feldspars and feldspathoids are present, and which are usually, if not always, derived from an alkali, and especially a soda-rich, magma. In Essex county they are confined to the immediate vicinity of Salem Neck, where they occur in large masses, accompanying and cut by the nepheline-syenite. They are quite distinct from this, and, so far as I know, few transition forms into this rock have been seen. On the other hand, they grade into the diorites of the neighborhood, so that in this direction it is difficult to draw a hard and fast line. These rocks have been described by Sears[3] and by Rosenbusch.[4]

They are dark gray or almost black rocks, of a granitic structure, and usually fine-grained, though varying to some extent in this respect. Biotite and feldspar phenocrysts and small round spots of augite and hornblende are seen in most specimens, but are not prominent. Specimens from one locality

[1] SEARS, Bull. Essex Inst. Vol., XXIII, 1891.

[2] ROSENBUSCH, Elem. d. Gesteinslehre, 1898, p. 171.

[3] SEARS, loc. cit.

[4] ROSENBUSCH, Mikr. Phys., p. 247, 1896.

on Salem Neck show a marked subschistose or platy structure. Rosenbusch has described the essexites of Salem Neck in considerable detail, and in general my observations agree with his descriptions. He has, however, included among the essexites proper certain rocks with what he calls a hyperitic structure, which, it seems to me, are not essexites proper, inasmuch as they contain neither alkali-feldspar nor nepheline, but constitute a dioritic facies of it.

In thin section the structure of the essexites proper is granitic, though the plagioclase shows a tendency to tabular development. The feldspar is mostly a plagioclase, showing clear twinning lamellæ, whose extinctions vary, but which correspond to compositions ranging from Ab_1An_1 to Ab_1An_2. Rosenbusch speaks of it as "hoch idiomorph," but for my specimens this is rather strong. It is certainly much more so in the hyperitic facies, while in the more normal essexites (such as the one analyzed), it is only rarely so. An alkali-feldspar is not uncommon, generally anhedral, and often microperthitic. This, and a microcline which is occasionally met with, are apparently rich in soda. Nepheline is fairly abundant, generally interstitial, but occasionally in well shaped crystals. I could not identify with certainty any of the sodalite seen by Sears.

Rosenbusch speaks of two remarkable peculiarities of the feldspars. The first consists of the presence, in gray dusty crystals or portions of crystals, of minute biotites, or hornblendes, about which there is a dust-free zone; the other is the presence of specks and veins of a colorless substance of low refrangibility, and either isotropic or faintly birefringent, which he thinks might be either glass or nepheline. Of the first of these I could find no example in my sections, and of the second only a little here and there which did not allow me to answer the question which Rosenbusch raises as to its nature.

In the typical essexite of Sears the most common ferromagnesian mineral is a deep green or greenish-brown, highly pleochroic hornblende, basal sections of which often show prismatic planes. This occurs scattered through the mass in

highly irregular grains and prisms, and also accompanying a colorless diopside, of which it seems to be an alteration product. The hornblende in this case is not rarely bluish-green, and apparently contains some soda. The pyroxene, which is not abundant, is a colorless diopside, usually in large crystals, and nearly always altered more or less to the green hornblende. It sometimes shows such brilliant polarization colors as to suggest olivine, but the fine straight cleavage lines and the oblique extinction prove it to be a monoclinic pyroxene. Small flakes and stout tables of a greenish yellow biotite are quite common. Titanite, often showing lozenge-shaped sections as well as in irregular grains, is abundant. Small grains of titaniferous magnetite are rare, and in nearly every case form the nucleus of titanite areas, which are apparently their alteration product. Long slender prisms of apatite are very abundant.

Specimens of the schistose variety vary a good deal. In a specimen given me by Mr. Sears the feldspars are largely in small anhedra, and the structure is microgranitic. Most of them are simple, perthites are not very common, twinning lamellæ rare. They have a brecciated structure and sometimes undulatory extinction, suggesting that the tendency to schistosity is due to pressure. Nepheline is present in considerable amount. Small irregular anhedra of a bright green aegirine-augite are scattered abundantly through the mass. A few large pale fawn-colored augites are seen, always more or less altered to a granular aegirite-augite. Small flakes of greenish-brown biotite and grains of titanite, often highly automorphic, are abundant, hornblende is almost wanting, and apatite scarce.

In other specimens the granitic groundmass is on a larger scale, the feldspars tabular and microperthite common, and interstitial nepheline abundant. An olive-green hornblende in beautifully automorphic crystals takes the place of the aegirite-augite, which is absent; large diopsides are rare, biotite almost wanting, titanite and apatite not abundant, and magnetite extremely scarce. No olivine was found by me in any of the varieties of the normal essexite.

The hyperitic variety is represented by two specimens from the southwestern part of Salem Neck, which only differ from Sears' type in being a little more coarsely crystalline, but much less so than the hyperitic diorites to be described later. The structure is somewhat ophitic, the feldspars being thick tabular, and the ferromagnesian minerals frequently xenomorphic towards them. At the same time these occupy bays and form inclusions in the feldspars, so that the crystallization must have been to a certain extent simultaneous. The chief peculiarity of the structure is the zonal growth of the biotite and hornblende about the pyroxene, olivine, and magnetite.

The feldspars are almost exclusively plagioclase, which is usually fresh, and with rather thick twinning lamellæ, whose extinction angles correspond to a basic labradorite, about Ab_1 An_3. Only a few grains of alkali-feldspar could be seen, and nothing which could be identified with nepheline. Olivine is present in some quantity, as rather large grains, usually automorphic though corroded. They are generally fresh, but sometimes partially serpentinized. A colorless or pale fawn-colored augite is present which shows high extinction angles. A reddish-brown barkevikitic hornblende is very abundant, showing the usual pleochroism; $\mathfrak{c}$=deep red-brown, $\mathfrak{b}$=deep red-brown, $\mathfrak{a}$=light brownish yellow, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. It seldom forms independent individuals, but nearly always occurs as a border about the pyroxene and olivine. This border, which is usually of the nature of a reaction rim between the pyroxene or olivine and the feldspar, is highly irregular, often of great relative thickness, and in many cases almost entirely replaces the pyroxene. A brown biotite which is present in less amount also occasionally plays the same rôle. Magnetite and ilmenite grains are abundant, and about them is almost constantly found a hornblende rim when they are included in pyroxene, while, if they are included in feldspar, this is less common. Apatite is rare.

An analysis was made of a specimen from Salem Neck which was given me by Mr. Sears as representing his type. An analysis of a similar specimen, made by M. Dittrich for Professor Rosenbusch is given in II.

	I	II		I	II
SiO^2	46.99	47.94	BaO	none	....
TiO_2	2.92	0.20	Na_2O	6.35	5.63
Al_2O_3	17.94	17.44	K_2O	2.62	2.79
Fe_2O_3	2.56	6.84	H_2O	0.65	2.04
FeO	7.56	6.51	P_2O_5	0.94	1.04
MnO	trace	....		———	———
MgO	3.22	2.07		99.60	99.92
CaO	7.85	7.47			

I. Essexite. Salem Neck. H. S. Washington anal.

II. Essexite. Salem Neck. M. Dittrich anal. (Rosenbusch. Elem. d. Gesteinslehre, 1898, p. 172. No. 1.)

The resemblance between the two analyses is close, the greatest differences being in ferric oxide, titanium oxide, and magnesia. It is possible that the low titanium oxide in Dittrich's analysis is due to the fact that it represents only the residue left after evaporation of the silica with hydrofluoric acid, while in mine, where the similar residue amounted to only 0.72 per cent., the titanium oxide was determined directly. The low silica and high lime and alkalies will be noticed, showing the basic monzonitic character of these rocks. Magnesia is rather lower than might be expected, a point which will be discussed later on.

Diorite.—This group is quite extensively represented in Essex county, the main occurrence being a long area with a general northeast-southwest trend in the western part, in Danvers, Topsfield, and Ipswich, a smaller area occurring about Salem and Marblehead and extending north into Beverly. From the large western area I have no specimens, all of mine coming from localities in the smaller areas about Salem and Marblehead. These rocks have been partially described by Sears[1] and are quite diversified in character.

Megascopically these are very dark, almost black, rocks, though a few are quite light, especially the main rock at Fort Sewall, Marblehead, which is a mottled light gray. This mass, by the way, is notable for the great number of "schlieren" and rounded masses of a dark, more basic diorite which it contains.

[1] SEARS, Bull. Essex. Inst., Vol. XXIII, 1891.

In structure they are always granitic, and in texture vary from rather fine to coarse-grain, the last looking like a typical diorite. The only minerals visible are white feldspars and black hornblende, biotite and augite.

Under the microscope it is seen that these rocks are essentially monzonitic in character, in Brögger's sense, orthoclase or an alkali-feldspar being almost invariably present along with the plagioclase, and that they vary from rather basic rocks rich in plagioclase and poor in orthoclase to more acid ones in which the orthoclase largely predominates over the plagioclase and where quartz also appears. The former closely approach the hyperitic varieties of the essexites, and, in fact, are only distinguished from these by their greater coarseness of grain and more dioritic appearance megascopically. The latter closely approach the akerites and perhaps should be described with them, but, on account of their intimate association with the dioritic rocks, and also because of their distinctly different megascopical character, they are placed here. Between these two extremes are found many transition types. The structure is always granitic or hypautomorphic, the dark minerals usually, but not always, having crystallized before the feldspars, the plagioclase generally before the orthoclase, and the quartz, if present, being always interstitial. None of the specimens are quite fresh, the best in this respect being some from near Collin's Cove, Salem Neck, which are hyperitic in structure.

The plagioclase, which has a tendency to stout tabular forms, is highly, and in many cases beautifully, twinned, according to the albite and pericline laws. It varies considerably in composition from an oligoclase, Ab_2An_1, to a basic labradorite, Ab_1An_3, the former being more abundant in the more acid orthoclase-rich varieties and the latter in the more basic, especially in specimens from Salem Neck. It is usually xenomorphic toward the ferromagnesian minerals, but not always, and is also met with as inclusions in the latter, so that it seems that, although the latter began to crystallize first, during a later stage the crystallization was simultaneous. Inclusions of augite,

magnetite and apatite are not rare. A quite common feature is the presence of numerous minute black rods which are square or long in section and are probably magnetite. In the specimen from Peach's Neck which was analyzed a reaction between augite and plagioclase has produced small flakes of brown biotite along the edges of the latter and extending into its substance. The alkali-feldspar is less automorphic than the plagioclase, and is often microperthitic. The quartz, which is abundant only in the main rock of Fort Sewall, is always interstitial and clear, with minute glass or liquid inclusions.

The ferromagnesian minerals vary much not only in amount but in kind. A colorless or almost colorless monoclinic pyroxene is most abundant. This corresponds in general to diopside, but in certain specimens, Peach's Neck, and in black "schlieren" at Fort Sewall, it has the habit of diallage, a parting parallel to (100) and (010) being prominent. The diopside shows high extinction angles and carries few inclusions. The diallage, which has a tendency to light brownish hues, is frequently crowded with minute magnetite (?) rods, which in sections parallel to (010) are arranged parallel with the direction of extinction, at an angle of 34° with the cleavage cracks. They also carry the small brown or opaque plates which are so frequent in the hypersthene of gabbros. These are not pleochroic and are apparently isotropic. In the hyperitic facies from Salem Neck the pyroxene is a light violet augite. The pyroxenes alter easily to uralite, brown hornblende, and biotite.

Primary hornblende is not abundant and is to be referred to two varieties. In the main rock of Fort Sewall and in specimens from Peach's Neck it is pale green or olive-green, not very pleochroic, and automorphic as well as fragmentary. In the basic hyperitic rocks of Salem Neck it is brown, much more highly pleochroic, and is apparently a barkevikite. Biotite, when primary, is greenish yellow or brown, the latter especially in the hyperitic forms. Secondary hornblende and biotite are extremely common, formed usually at the expense of the pyroxenes, and often in the form of reaction rims. A few crystals of

olivine entirely altered to serpentine were seen, but they are too rare to be of any importance. Magnetite is abundant in all the specimens, usually in large rounded grains. There seems to be a tendency for biotite to be produced from it when included in feldspar and hornblende when in augite, but this rule is not constant. Apatite is abundant in fair-sized stout crystals, more so in the basic than in the acid varieties.

It is evident that the rocks which are grouped under the heading of diorite are highly varied and that they represent transition forms from the essexites to the akerites. This is true at least for the area under examination; of the larger Danvers-Ipswich area I can say nothing. For the satisfactory study of these rocks several analyses will be necessary, but at present only one is available. The rock chosen for analysis was a specimen from the south side of Peach's Neck, a coarse-grained dark rock which shows under the microscope plagioclase, less orthoclase, no quartz, diopside, diallage, magnetite, apatite, and secondary hornblende and biotite. It is not quite fresh, but not altered enough to affect the result seriously.

SiO_2	51.82	CaO	8.59
TiO_2	2.15	Na_2O	3.44
Al_2O_3	17.06	K_2O	1.77
Fe_2O_3	1.97	H_2O (110°)	0.11
FeO	8.60	H_2O (ignit.)	0.20
MnO	none		100.58
MgO	4.87		

This is evidently the analysis of a diorite, though a basic one, the silica and alkalies being too high for a gabbro. It will be discussed later.

Quartz-augite-diorite.—The rocks which Sears calls by this name occupy a narrow area west of the rocks described in the preceding pages, which stretches through the county in a northeast-southwest direction from Andover to Newburyport and the New Hampshire line. Representing them I have only three specimens from Newburyport, given me by Mr. Sears, by whom they have been briefly described.[1] They are light gray, medium-

[1] SEARS, Bull. Essex Inst., Vol. XXVII, p. 7, 1895.

grained, granitic rocks, showing feldspars, augite, and a few quartz grains. The feldspars are apt to be epidotized. In thin section they show a granitic structure, and are composed of a rather basic plagioclase, about Ab_1An_2, nearly as much orthoclase, considerable quartz, stout prisms of pale green diopside which is commonly uralitized, some pale green biotite also altered, little or no magnetite, and rare small apatites. As all the specimens were badly decomposed I made no analysis of them, but they presumably approach in composition the nordmarkites.

Porphyritic diorite.—A peculiar rock which may be called a diorite is found, along with the orbicular syenite, in similar rounded masses enclosed in granite, near Bass Rock. It is dark-brown, with a rather fine-grained granitic groundmass of white feldspar tables and hornblendes, often surrounded by white feldspar zones, lying in a finer-grained matrix. Through this are scattered large phenocrysts of labradorite, up to 5^{cm} in length, of a peculiar clove-brown color and thick tabular habit. The cleavage of these is very good, and on basal cleavage surfaces fine twinning striations are visible.

Under the microscope the groundmass shows a granitic structure, composed largely of alkali-feldspar, with some plagioclase, small grains of colorless diopside, pale brownish-green hornblende, rare biotite flakes, considerable magnetite in grains and small stout rods, quite abundant apatite and no quartz. The large phenocrysts show well developed twinning lamellæ, which give extinctions corresponding to a labradorite of the composition Ab_2An_3. They are dusty with minute liquid inclusions holding movable bubbles, and also carry inclusions of diopside, hornblende, and magnetite. An analysis was made of a rather coarse-grained piece which was chiefly phenocryst, and this gave:

SiO_2	54.99	CaO	9.87
TiO_2	0.29	BaO	none
Al_2O_3	25.58	Na_2O	4.95
Fe_2O_3	0.43	K_2O	1.11
FeO	2.70	H_2O	0.38
MnO	trace		
MgO	0.72		101.02

This may be calculated roughly to represent:

Orthoclase,	6.5	Diopside,	2.1
Albite,	42.0	Hornblende,	3.2
Anorthite,	44.2	Magnetite,	2.1

Here the albite and anorthite molecules are in the ratio of 1 : 1, but since the microscope shows that the plagioclase has the composition of about Ab_2An_3, it is evident that the alkali-feldspar is rich in soda, and has approximately the composition Or_1Ab_2. The analysis, however, does not represent the composition of the rock as a whole, and for most purposes is of little or no use.

Gabbro.—Rocks which belong to this group are found in typical development only at Nahant, and are called norites by Sears, who has briefly noticed them.[1] According to Wadsworth[2] and Sears, gabbros also occur at various localities in Essex county, especially at Davis' Neck, Cape Ann, and Woodbury Point, Beverly. These, however, judging from the somewhat unsatisfactory specimens in my possession, are rather diorites in Brögger's sense, but will not be described further.

The gabbro of Nahant, as represented by the few specimens collected by myself, are dark, coarse-grained rocks composed of plagioclase, which even in the freshest specimens are dull or waxy and greenish through epidotization and black augite, besides titaniferous magnetite grains. They show both megascopically and in thin section a typically granitic structure.

The abundant plagioclase, although rather decomposed, shows twinning lamellæ whose extinctions correspond to those of a basic labradorite about Ab_1An_3. A little orthoclase is also present. A pale gray augite is abundant, which is often automorphic and shows constantly high extinction angles. In my specimens I could find none of the hypersthene mentioned by Sears. Large titaniferous magnetite grains are common and are often surrounded by borders of leucoxene. With the exception of limonite, epidote, chlorite, and a few other decomposi-

[1] SEARS, Bull. Essex Inst., Vol. XXVI, 1894.

[2] WADSWORTH, Geol. Mag., 1895, p. 208.

tion products, these are the only minerals present. An analysis was made of the freshest specimen, which was slightly altered, from near a cove on the north shore of Nahant, east of the village.

SiO_2	43.73	Na_2O	2.42
TiO_2	4.23	K_2O	1.45
Al_2O_3	20.17	H_2O (110°—)	0.08
Fe_2O_3	4.32	H_2O (110°+)	1.02
FeO	6.93	P_2O_5	0.15
MnO	none		
MgO	3.91		99.40
CaO	10.99		

It is low in silica, rich in lime, but rather poor in magnesia, high in titanium oxide and alumina, and rather high in alkalies for such a rock, which is evidently a true gabbro.

ADDENDUM

"*Hyperitic diorite.*" — Since the description of this rock was put in type an analysis has been made, which renders necessary some corrections and additions. The analysis is given here.

	I	II
SiO_2	45.32	49.25
TiO_2	1.94	1.41
Al_2O_3	18.99	16.97
Fe_2O_3	3.78	15.21
FeO	9.78	
MnO	....	trace
MgO	4.68	about 3.00
CaO	9.19	7.17
Na_2O	3.78	4.91
K_2O	2.12	2.01
P_2O_5	....	0.76
H_2O (110°)	0.09	about 0.30
H_2O (ignit.)	0.31	
	99.98	100.99

I. Hornblende-gabbro, Salem Neck. H. S. Washington anal.

II. Olivine-gabbro-diabase, Dignæs, Gran. A. Damm and L. Schmelck anal. (W. C. Brögger. Quart. Jour. Geol. Soc., Vol. L, p. 19, 1894.)

It will be seen that the rock is decidedly more basic than the other diorites of the region, so far as I am acquainted with them. The silica in fact is lower than that of the diabase and essexite, and closely approaches that of the gabbro from Nahant. This being the case, and the characters otherwise corresponding, the rock is not a diorite in the proper sense, as used by Brögger,[1] but should be called a hornblende-gabbro. It was thought at the time of the microscopical examination that the rock was basic, but it was not expected that it would turn out to be so low in silica as the analysis shows. At the same time the character of the hornblende, which is essentially a barkevikite, the rather high alkalies, and the association with essexite and foyaite show that these hornblende-gabbros ("hyperitic diorites") are decidedly distinct from the other diorites, and approach more closely the essexites and the more soda-rich rocks of the region. Attention has already been called to the fact that they grade into the essexites, and that Rosenbusch grouped them with these, but their decidedly lower alkali content and lack of orthoclase and nepheline sufficiently distinguish them.

It is to be remarked that these rocks resemble very closely under the microscope some of the gabbros of Norway, especially those from the district of Gran, and above all, some from the Viksfjeld. This is seen on microscopical comparison of sections of the rocks, some being mutually indistinguishable, and is also shown by the analyses, one of those of the Gran rocks being given in II for comparison.

H. S. WASHINGTON.

[1] W. C. BRÖGGER, Die Eruptivgesteine des Kristianiagebietes, Vol. I, p. 93, 1894, and Vol. II, p. 35, 1895.

THE SWEETLAND CREEK BEDS[1]

In Muscatine, Bloomington, Sweetland, and Montpelier townships, of Muscatine county, Iowa, some argillaceous beds are frequently found overlying the Cedar Valley limestone These contain a fauna quite different from that of the latter, and are unconformable with this as well as with the Coal Measures above. For reasons which will presently appear it is proposed to call them the Sweetland Creek beds.

Typical exposures.—Following the north bluffs of the Mississippi westward, the first occurrence of these beds is to be seen in the bank of a creek which comes down from the north, just east of the town of Montpelier. About twenty rods north of the bluffs the basal sandstone of the Coal Measures rests on some olive-gray shale, with green bands, rising about three feet from the bed of the stream in the right bank. This shale is altogether unlike the dark shale of the Coal Measures in appearance. The layers are more even and uniform. An unconformity between the two is also evident, and the lower formation soon disappears. In the river bluff the same creek is undermining a cliff of Coal Measure rock, which rests on the Cedar Valley limestone for the greater part of its length, but at the south end the base of the Coal Measures rises somewhat abruptly, first on an eroded slope of the limestone, and then over some decayed yellow clayey beds which intervene and run up ten or twelve feet above the limestone. The present condition of the bank does not afford an opportunity to closely study the nature of the clay beds, but in all probability they belong to the same strata as the shale above.

To the west of the town, a short distance up in Robinson Creek, and just northwest of Mr. G. W. Robinson's residence, some green clay is seen in the south bank of the creek, appar-

[1] Published by permission of the State Geologist of Iowa.

ently resting on the eroded surface of the Cedar Valley limestone. At the base of this clay there is a thin layer of more stony material, and this contains specimens of *Ptychtodus calceolus* and other small fish teeth. This is the basal layer of the Sweetland Creek beds. About one half mile farther up the same creek near the north line of section 23, in Montpelier township, just below a small fall in the creek, the following section is seen.

Number		Feet
13.	Coal Measures.	
12.	Dark bituminous shale with two or three bands of green shale; the dark next the green exhibiting a complex network of thread-like green extensions from ½ to 2^{mm} in thickness, lying approximately parallel with the bedding. Occasional lingulas found	1
11.	Dark bituminous shale with small spheroidal crystalline nodules of pyrites, occasional lingulas and *Spathiocaris emersoni* - -	2
10.	Concealed (next number a few rods farther down) - - -	2 ?
9.	Light greenish shale - - - - - - - - - -	1
8.	Dark olive-gray shale - - - - - - - - -	⅔
7.	Green shale - - - - - - - - - -	⅔
6.	Greenish calcareous shale, almost stony, containing cylindrical or flattened fucoid markings slightly more greenish than the matrix	⅛
5.	Dark gray shale - - - - - - - - - -	1
4.	Grayish-green pyritiferous rock with minute fragments of unrecognizable fossils - - - - - - - - -	¼
3.	Dark gray shale - - - - - - - - - -	¼
2.	Greenish-gray somewhat stony shale exhibiting concretionary conchoidal fractures when weathered - - - - -	¼
1.	Greenish-gray argillaceous and pyritiferous fine-grained dolomitic rock in layers a few inches in thickness, with fucoid impregnations or markings like those in number 6, ¼ inch in diameter -	1⅔

At the south end of this outcrop there is a small displacement in the ledges, which, dipping at a considerable angle south of it, soon disappear under the Coal Measures. The displacement is no doubt local and probably due to the falling in of some cavern in the underlying limestone.

Westward for the next three miles these beds do not appear, although the contact between the Coal Measures and the Cedar Valley limestone frequently comes into view. In the Pine Creek

basin they must have been removed by erosion previous to the deposition of the Coal Measures. Their next appearance is in Schmidt's run, about a mile east from the railroad station at Fairport. Just north of the wagon road under the bluffs they may be seen in the left bank of the run. There are several outcrops farther up, and the following section was made out, unconformably overlaid by the Coal Measures.

Number		Feet
4.	Dark, almost black shale, with green seams from one to four inches thick, near which the darker shade exhibits a net work of filamentous extensions of green clay	7
3.	Greenish light colored shale	3½
2.	Greenish stony and hard shale	½
1.	Greenish gray soft shale	1½

Just west of the railroad station at Fairport, where a wagon road follows a ravine up the bluff, this ravine exposes the following section.

Number		Feet
7.	Coal Measures resting unconformably on the numbers below.	
6.	Weathered shale of alternate light and dark layers	5
5.	Dark gray shale	5
4.	Grayish-green shale with two bands of darker shale in part perforated by coarse curving filaments or cylinders of green shale	3
3.	Concealed	2 ?
2.	Dark gray shale with curving cord-like cylinders of green shale about ⅛ inch in diameter	3
1.	Greenish argillaceous dolomite in layers about 6 inches in thickness	1

In a small ravine which comes down from the west side of Wyoming Hill there is seen under and north of the wagon bridge about eight feet of gray and green shale with some stony layers. The Cedar Valley limestone comes out in the river bank just below and the Coal Measures overlie the exposure, rising about 100 feet above it.

Along Sweetland Creek the relation of these beds to the formations above and below them is better exhibited than at any other place in the county. About one-third of a mile north from the river bank they come out into view on both sides of

the creek, and they are also seen in a small tributary which runs into the creek from the east. Combining all the exposures at this point the following succession of separate layers is evident.

Number		Feet
11.	Dark gray bituminous shale with one or two thin green bands about four feet below the highest exposure. Occasionally small flat concretions of pyrites are seen. Next the green layer the shale is dark filled with a maze of fine green filamentous lines. Drift overlies	8
10.	Dark shale containing lingulas, *Spathiocaris emersoni, Rhynchodus,* and a fossil resembling *Solenocaris strigata.* This number is continuous with No. 11	1½
9.	Greenish clay with flat concretions of iron pyrites frequently having white stony lamellar extensions from the margin	3
8.	Dark shale	⅔
7.	Greenish stony shale with a conchoidal concretionary fracture,	⅓
6.	Hard light grayish-green shale with white flattened cylindrical fucoid concretions of a concentric structure in horizontal positions	¼–½
5.	Greenish argillaceous or arenaceous fine-grained dolomite in ledges from 4 to 10 inches in thickness, with occasional lingulas and a fragment of a cast of a gasteropod near the base, frequently exhibiting small cylindrical concretionary impregnations of a deeper green, and occasionally impressions of plant-like fibrous structure covered with a thin layer of bituminous material	3
4.	Greenish shale	1½
3.	A stony seam filled with finely granular pyrites and occasionally showing larger lumps of the same mineral in one instance associated with plant-like fibrous impressions, frequently containing rounded worn fragments of fish teeth	½–¼
2.	Green hard shale	⅔
1.	Greenish stony layer with frequent, mostly rounded, fragments of *Ptychtodus calceolus*	⅓

Under the lowermost layer containing fish teeth the uneven surface of the upper ledges of the Cedar Valley limestone is seen, and at least eight feet of this rock is exposed. In some of the shallow depressions in its upper surface a seam of black bituminous material is found. At one point this forms a layer two inches in thickness. Near the south end of the exposure farthest down the creek the upper beds come down over the

uppermost ledge of the limestone, which runs out as if worn away. The surface of the limestone has been partly uncovered by the creek. It is brown in color, uneven from erosion and frequently studded with nodules of iron pyrites or covered by a continuous incrustation of the same mineral. In the west bank of the creek the basal sandstone of the Coal Measures overlies the eroded edges of numbers 6, 7, and 8 in the above section, which rise under it in a hillock. In the gully to the east the section is continued higher up and the Coal Measures do not appear. Some distance farther up Sweetland Creek they are again seen unconformably overlying the dark gray shale in the east bank, with erosion contours extending down three feet into the lower formation. At this place the basal conglomerate contains rounded lumps of the dark shale, three or four inches in diameter. Still farther up the creek the darker shale corresponding to number 11 in the above section appears at several places in the bed of the stream, rising in one instance about five feet in the bank. The last seen is about one hundred paces south from the wagon bridge near the north line of section 27. In each of these places the characteristic green layers with their accompanying network of green threads in the confining dark shale may be seen.

About three fourths of a mile west of Sweetland Creek, near the east line of section 28, in Sweetland township, a smaller stream exposes the following section.

Number		Feet
5.	Coal Measures.	
4.	Alternate layers of dark and greenish shale - - - - -	4
3.	Fine grained, light yellowish-gray, impure dolomite in thin ledges	2½
2.	Greenish shaly rock with a thin, harder layer below - - -	2¼
1.	Upper ledges of the Cedar Valley limestone, ferruginous and worn superficially - - - - - - - - - -	1–2

In Camhel Run, which comes down to the river through the northwest corner of section 21, in the same township, a similar succession of layers is seen at the point where the stream passes the line of the river bluffs. The following section appears very clearly.

Number		Feet
11.	The base of the Coal Measures.	
10.	Dark gray shale with lingulas near the base	3
9.	Greenish shale	3½
8.	A layer of harder, almost stony shale	½
7.	Greenish-gray shale weathering with a conchoidal fracture into small spheroidal nodules and chips	1±
6.	Grayish, fine grained, impure dolomite	1½
5.	Greenish shale	1±
4.	A thin and stony, in places highly pyritiferous seam, associated with small selenite crystals when decayed, in places almost filled with rounded specimens of *Ptychtodus calceolus*	1/10–½
3.	Greenish shale	½–1
2.	Greenish fine-grained rock with fish teeth	1/6–¼
1.	Upper ledges of the Cedar Valley limestone with a slightly eroded surface, frequently covered with pyrites.	

Number 10 in the above is seen in two or three places farther up in the creek, but it soon disappears under the base of the Coal Measures.

Along Geneva Creek, in the northwest quarter of section 29, in the same township, the basal layers of the preceding sections are seen in the bed of the stream opposite the Geneva schoolhouse, and below the wagon bridge. The main stony ledge forms the bed of the creek for a distance of ten or twenty rods a quarter of a mile farther up. About half a mile north of the schoolhouse the shale above this ledge rises some six feet in the west bank, and is overlaid by the basal conglomerate of the Coal Measures, from which a small spring issues. Combining these exposures the succession of the layers seen may be given as in the following section.

Number		Feet
13.	Basal conglomerate and sandstone of the Coal Measures.	
12.	Dark gray and ferruginous, evidently somewhat disintegrated dark shale	½
11.	Light greenish-gray shale	½
10.	Dark lavender colored shale	1⅙
9.	Green shaly rock	½
8.	Concealed	?
7.	Green rock in even thin layers with regular vertical rather equidistant joints	1½

Number		Feet
6.	Concealed	?
5.	Greenish shale (opposite the schoolhouse)	1
4.	Pyritiferous green stony layer with cylindrical straightish fucoid impregnations	⅛
3.	Green shale	1
2.	A conglomerate of fish teeth, containing *Ptychtodus calceolus* and *Synthetodus* frequently in a worn condition and imbedded in a greenish argillaceous fine-grained dolomite	¼
1.	Beds of the Cedar Valley limestone containing large fragments of Stromatopora, with the upper surface unevenly eroded.	

From this point westward no more is seen of the beds under consideration until we come to East Hill, in Muscatine. Under the south bluff of this hill the railroad bed has been excavated in the upper dark shale seen in the foregoing sections. These rise here about thirty feet above the bed of the road, and they have been so disposed to slip in the bank, that piles and a stone-wall have for many years been needed to keep the embankment from coming down on the track. These were removed late last fall and the face of the embankment was cut away several feet. This work left the shale well exposed. The section above and below the railroad bed is as follows.

Number		Feet
2.	Dark or gray bituminous shale, with three parallel bands of green shale a few inches in thickness and about three or four feet apart, weathering into fine chips of a yellowish light gray color, containing small flat concretions of pyrites, joints in some of the freshly exposed shale filled with numerous small crystals of lenite disposed in branching patterns, the basal part containing sea lingula and exhibiting the peculiar network of green thread-like extensions observed in previous sections near the transitions to green shale	36
1.	Green shale	2

The top of number 2 is unconformably overlaid by the Coal Measures, and has evidently been weathered previous to their deposition. Below number 1 the section is concealed in the river bank. The base of this layer is about ten feet above low water. There is little doubt that it is the equivalent of number

9 in the Sweetland Creek section, and the lower layers of these beds may possibly all have been exposed above water at this point before the railroad embankment was made. As these lower layers aggregate about seven feet in thickness at other places, it will be noticed that the extreme thickness of the whole formation at this place is about forty-five feet. This is the greatest thickness that has been seen anywhere in the county.

Just above the wagon bridge which crosses Mad Creek near the center of the northwest quarter of section 24 in Bloomington township, some ledges equivalent to numbers 6, 7, 8 and 9, in the Sweetland Creek section appear in the bank of a tributary from the east. Again in the creek running east through the north half of the northwest quarter of section 26 in the same township some thin ledges of rock and some green shale corresponding to numbers 3, 4, and 5 in Sweetland Creek come into view from under some Coal Measure beds.

Geographical distribution.—So far as known, the above places include all the exposures of the Sweetland Creek beds in the county. There is good reason to assume that they underlie the Coal Measures in most of Muscatine, Bloomington, and Sweetland townships, and that scattered outliers occupy the same position in the east half of Montpelier township. In all probability their outcrop in the river bluff is continuous from Wyoming Hill to Muscatine, though mostly concealed by the talus under the bluffs.

General section.—The separate layers and ledges of the formation have a remarkably uniform development, varying but slightly in different places. The basal layer, though only about three inches in thickness, can always be recognized in its place, and invariably contains the characteristic fish teeth. From six inches to a foot above this layer there is a pyritiferous stony seam from one-half to two inches in thickness, and this is readily identified in all the creeks in Sweetland township where the lower part of the section appears. The peculiar maze of green threads which extend into the dark shale where this comes into contact with green layers have been observed in almost every case where

they are due in the section, all the way from Muscatine to Montpelier. It is therefore no very difficult task to combine the local outcrops into a general section.

GENERAL SECTION OF THE SWEETLAND CREEK BEDS

Number		Feet
7.	Dark bituminous shale, occasionally containing small flat concretions of iron pyrites, with three thin bands of greenish shales respectively about 5, 9, and 12 feet from the base	33
6.	Dark shale, with thin seams of blue shale, the dark containing two species of lingula, *Spathiocaris emersoni*, *Rhynchodus*, and a fossil resembling *Solenocaris strigata*	3
5.	Greenish shale, with occasional stony layers, containing flat concretions of pyrites frequently bordered by lamellar marginal extensions of a white dolomitic material	3½
4.	Alternating layers of greenish stone and green and dark shale, the latter in part containing a network of thread-like extensions of the former. The green shale has elongated flattened concretions resembling fucoid growths and lying parallel with the bedding. The stony layers are frequently charged with small grains of pyrites and contain minute fragments of fossils	2
3.	Greenish fine-grained argillaceous magnesian limestone impregnated with iron pyrites and calcium phosphate, in ledges from 4 to 10 inches in thickness, with cylindrical fucoid impregnations slightly more greenish than the matrix and from 3 to 6 millimeters in diameter, containing two species of lingula, a fragmentary cast of a helicoid gasteropod, and imprints of some fibrous structure like that of some plant stem	3½
2.	Hard greenish-gray shale, with a stony pyritiferous layer that contains fish teeth and impressions of vegetable tissue about 10 inches from base	3
1.	Argillaceous dolomitic stony layer containing *Ptychtodus calceolus* and other forms resembling *Synthetodus*	¼

Lithological peculiarities.—The greenish ledges turn grayish-yellow on weathering. The main stony ledge, number 3, often protrudes as a shelf over the clay below it, which is more easily removed by erosion. In two instances an efflorescence of epsomite was noticed forming on the face of the clay thus protected from rain by the overhanging rock. The material found in the shells of the lingulas of this ledge was unaltered, but

in one instance slightly dissolved away. The tubular impregnations in the stony layers of the formation appear to be marked off from the mass of the rock so as to sometimes weather out like casts of fucoid stems. In other instances they appear like slightly more colored parts of the rock. The thread-like extensions of green clay which form a network in the dark shale at some horizons where it comes in contact with the lighter shale vary in coarseness at different places. There is nothing to indicate a structural boundary between the green in the threads and their dark matrix, and there is hardly anything to suggest that they have an organic origin. It seems more likely that they have resulted from some progressive change in the mineral nature of the shale. Excepting the lingulas, the fossils which occur in the layer numbered 6 in the general section are all of a black and bituminous substance, which is apt to break and fall out in drying, leaving only a mold. The dark shale in numbers 6 and 7 is fine and very uniform in character. Occasionally it is difficult to distinguish from the Coal Measure shale, but the latter usually contains small mica scales, which are absent from the former. Where not weathered, these beds contain a considerable amount of bituminous material, which on distillation yields inflammable gas and oil. The several layers of the formation have been examined for phosphate by Dr. J. B. Weems, who finds 2.01 per cent. in number 7, 1.94 per cent. in number 6, 2.09 and 2.18 per cent. respectively in two analyses of material from number 5, 3.18 per cent. in number 4, 6.82 and 5.29 per cent. respectively in two analyses of material from number 3, 5.43 per cent. in number 2, and 4.86 per cent. in number 1.

Structural Relations.— As already shown, a pronounced unconformity separates this formation from the overlying Coal Measures. The erosion interval preceding the deposition of the latter has left its marks, not only in the reliefs which extend from the top of these beds to a considerable distance below their base into the underlying limestone, but also in the weathering of the Sweetland Creek beds, especially where these rise

high. In such places the lamination appears indistinct, and the shales are oxidized and leached. After the deposition of the Sweetland Creek beds they were raised and subjected to erosion and sculpturing, which no doubt removed the greater part of them. Only remnants are left. Then, again, the land was submerged, and the topography just sculptured was covered over by the variable shore deposits of the Coal Measures.

It has also been shown that there is an unconformity with the underlying Cedar Valley limestone. But this unconformity indicates altogether different conditions. The upper formation is, in this case, not a shore deposit. The basal member of the Sweetland Creek beds is a thin layer of argillaceous dolomite containing no littoral detritus, and it is unusally uniformly developed, though only two or three inches thick. It is a sediment made in the sea at such a slow rate that the teeth of dying fishes accumulated rapidly enough to make at one place as much as one fourth of its bulk. This layer follows the small inequalities in the surface of the lower rock like a mantle. None of these are very high or deep. On a distance of a few rods none appear to exceed two feet in vertical extent. Near the Geneva school the basal tooth-bearing layer appears to occupy a place eight feet lower than the highest ledge in an abandoned quarry close by. The surface of the limestone is, however, plainly eroded and apparently to some extent oxidized. In the east bank of Sweetland Creek the highest ledges of the limestone run out to the south, and the overlying formation comes down over their beveled edges. An unconformity of this kind is most likely caused by subaqueous erosion, due to marine currents, followed by renewed sedimentation in the same sea. Such events may have been accompanied by an approach of the shore line. This is, perhaps, indicated by the presence of faint traces of vegetation in the later member in this case. But at the very beginning of the second accumulation the shore was not near enough to leave a trace of anything coarser than clay. Even this was scarce at first, when calcareous sediments predominated. The persistence of each thin layer over distances of several

miles goes to show that the conditions under which they were laid down were uniform over wide areas, and such conditions are not to be found in the proximity of the shore line. Everything considered, this unconformity was most likely caused by changed conditions in the sea and its currents, in all probability consequent upon some orogenic movements affecting the ocean basin.

Fossils.—The fossils so far found in this formation are few, but they are many enough to indicate that it must be referred to the Upper Devonian, or the Chemung. The fibrous plant-like impression from number 3 was found extending over a slab a foot long and about three inches wide. In the pyritous layer in number 2 there was a similar, much smaller, impression. The mold in both instances was covered by a bituminous crust an eighth of an inch in thickness. In this no organic structure could be detected. The lingulas which occurs in numbers 3 and 6 have been submitted to Dr. Charles Schuchert, who says that one species is apparently identical with an undescribed species, from nodules in the "Black Shale," or the Genesee; one is related to *L. melie* Hall, from the Cuyahoga shale; and another to *L. nuda* Hall, from the Hamilton. The author has also observed one lingula in number 6, which resembled *L. subspatulata* M. and W. Some small bilobate fossils from the same number in the general section have been examined by Dr. J. M. Clarke, who has reported that they are identical with *Spathiocaris emersoni* Clarke. This fossil occurs in the Portage group in New York, and has not previously been reported from the West. In the same layer the author found one fossil which resembled *Solenocaris strigata* Meek. This form is known to occur in the "Black Shale" of the Ohio valley. The cast of a gasteropod, found in the stony ledge number 3, was too fragmentary for more exact determination. Dr. C. R. Eastman has examined all the fish remains found, and states that the greater number of the teeth from numbers 1 and 2 are *Ptychtodus calceolus* M. and W. He finds them on the average smaller than usual, but in other respects perfectly like the type. He also reports that there are several other forms of flat, crushing teeth, which are allied to

Synthetodus from the State Quarry fish bed in Johnson county. From the bituminous dark shale, number 6, he identifies a Rhynchodus, related to *R. excavatus* Newb., from the Hamilton in Wisconsin.

LIST OF FOSSILS IN THE SWEETLAND CREEK BEDS

Impression of plants.	
Lingula, sp. undet.	Identical with one from the Black Shale
L. cf. melie Hall	Cuyahoga Shale
Lingula, cf. nuda Hall	Hamilton
Lingula subspatulata M. and W. (?)	Black Shale
Spathiocaris emersoni Clarke	Portage Shale
Solenocaris strigata Meek (?)	Black Shale
Gasteropod	
Ptychtodus calceolus M. and W.	Hamilton and State Quarry Beds
Synthetodus	State Quarry Beds
Rhynchodus, cf. excavatus Newb.	Hamilton

Additions will no doubt be made to this list. As it is, it indicates a correlation with the Upper Devonian of New York, and more particularly with the Devonian Black Shale of the interior, which also is regarded as a part of the Upper Devonian. To this shale it shows another resemblance in having the basal layers stony and containing a comparatively high per cent. of calcium phosphate, while the upper part is a black shale. It will be remembered that in Perry and Hickman counties in Tennessee the Black Shale changes downward into the phosphate rock.[1]

This comparison may be better shown in tabular form.

RELATION OF DARK SHALE TO PHOSPHATE BEARING ROCK IN IOWA AND IN TENNESSEE

Iowa		Tennessee
Bed No. 7 contains 2.01 % of phosphate	Dark Shale	Black Shale containing little or no phosphate
" " 6 " 1.94 % " "		
" " 5 " 2.13 % " "		
" " 4 " 3.18 % " "	Variable beds	
" " 3 " 6.05 % " "	Greenish gray pyritiferous rock and shale	Light gray to bluish-black phosphate rock, with disseminated pyrites
" " 2 " 5.43 % " "		
" " 1 " 4.86 % " "		

[1] See the Tennessee Phosphates, by C. W. HAYES, Seventeenth Ann. Rep. U. S. Geol. Surv., Part II.

The indicated correlation appears all the more probable, as there exists under the phosphate-bearing rock in Tennessee an unconformity, which is believed to be due "not to the existence of a land area and subaërial erosion, but rather to non-deposition, by reason of strong marine currents."[1] The renewal of the conditions of sedimentation in the paleozoic sea in the late Devonian age may not have been quite simultaneous in the two localities, though nothing is known to indicate the contrary, but there seems to have been at any rate a parallel in the sequence of events.

J. A. UDDEN.

[1] Loc. cit., p. 534.

STUDIES IN THE DRIFTLESS REGION OF WISCONSIN

In my previous articles under the above title I have stated that no glaciated material had up to that time been found. Indeed I was not very hopeful that any would be found, for not only are the beds concealed to a very large extent, but the parts exposed are those which would naturally be composed of superglacial and englacial material. Add to this the fact that the glaciers if really prescribed, were but a few thousand feet long at the utmost, and the further fact that even of this short distance a considerable portion was over loess of earlier deposition and it will be seen that such material must necessarily be scanty. Nevertheless in view of the extreme difficulty of determining the original aspect of the beds in many important particulars it was very desirable that the evidence which could be furnished by glaciated material should be added to that already given. I think it very fortunate therefore that during the past summer I have discovered a bowlder which gives very strong if not decisive indications of glacial abrasion, and inasmuch as it will form a most important part of the evidence for the existence of glaciers I will describe it in considerable detail.

The bowlder lies at the bottom of a ravine, well within one of the smaller valleys. It is about 10 in.×14 in.×26 in. in dimensions. The material is a rather hard, course-grained ferruginous sandstone, such as occurs a little below the base of the Lower Magnesian limestone. Its rather rough uneven surface is the product of prolonged weathering, but at one end there is a facet forming an irregular oval about 6 in.×8 in. which contrasts strongly with the rest, being nearly flat, and very noticeably smoother to the touch. Examination with a lens shows that this smoothness is due to the relatively small projection of the individual sand grains, few standing out more than a third of their diameter above the general surface, while on the

weathered portions they often project nearly their entire diameters.

It is evident that the resistance of the sand grains to abrasion was greater than the strength of the cementation, so that the abrading agent removed them integrally instead of wearing them down to a common surface. There is, however, near one edge of the facet a small concretionary nodule within which the great abundance of iron furnishes a strong cement. In this the individual grains *are* worn to a common surface, the effect being equal to the best examples of glacial polish. A portion of this concretion passes over onto the weathered surface where the grains are all entire, and owing to the strong cementation many of them are held as the capping of little pedicels, giving a very rough surface. The bedding plane of the bowlder is parallel to its longer diameters, and the flattened facet is nearly perpendicular to this. The facet is crossed in a direction perpendicular to the bedding plane by a straight groove about ¼ in. wide and deep enough to render it perfectly distinct. Other markings are but faintly shown, but so far as they are distinguishable they are parallel to the groove.

It appears quite evident that this abraded facet was superimposed on an originally weathered surface, for sundry depressions occurring within it were not affected by the abrasion, but still retain their original weathered character. Taking all these features into consideration I think it may be said that they are such as are characteristic of glacial abrasion, while it is hard to suggest another agent by which they could have been produced. Certainly none which we have the least reason to believe was operative in the locality.[1]

I have mentioned that the bowlder lies at the bottom of a ravine. It may therefore be well to add that although it is exposed to the action of the occasional torrents, yet the facet in question is turned away from them, while that portion which

[1] It would seem that abrasion of this kind and extent might be within the competency of the friction to which ordinary talus is liable to be subjected in descending a slope.—Ed.

does receive their impact (and has certainly for a long time) is indistinguishable from the rest of the weathered surface. But the results of torrential abrasion are so different from those described that it need not be seriously considered as a possible agent.

If this be a case of glacial abrasion, and it is difficult to resist such a conclusion, it must necessarily decide the question as to the existence of small local glaciers, since its situation is such that if glaciated at all it was certainly the work of such local glaciers.

It was my hope during the season just passed to make a series of observations at critical points with a view to a more definite determination of certain doubtful features, but owing to a pressure of other work they were for the most part left incomplete. On two points, however, evidence of considerable value was obtained. The first relates to the frontal characteristics of the bowlder beds, especially the frontal slope. This appears to have been normally steep as compared with the portion immediately back of it along the axis of a valley.

This characteristic is shown in two or three of the beds which fail to reach the present river level, but as they fall within the limits of the highest terrace it is open to question whether the effect was not due to erosion when the river was at that stage. But I have ascertained that the same characteristic is found in beds which terminate a hundred feet or more above this level. Still another bed extends to the present river level and has been truncated by river erosion, but gives no indication of erosion at the higher level, although by situation it was especially exposed to erosive action — far more so than the other beds which were well protected from currents.

The second relates to the disposition of the beds along the sides of the valleys showing that on reaching their rocky sides the beds rise to higher level than along the axes of the valleys, This is not hillside wash since the material is foreign to the hills on the sides of which it occurs.

Assuming these beds to be glacial an interesting question is

raised as to their synchronism with the successive phases or epochs of the glacial period.

Before this can be answered other than conjecturally it will be necessary to correlate them with the succession of non-glacial deposits filling the larger valleys of the driftless region, a work of considerable difficulty.

G. H. SQUIER.

A DISCUSSION AND CORRELATION OF CERTAIN SUBDIVISIONS OF THE COLORADO FORMATION

A FAIRLY accurate correlation of the subdivisions of the Colorado formation in the central-interior province is not difficult. Although the work done in the different areas of the province has been largely independent, yet divisional lines are not strikingly inharmonious. Points of separation are more easily determined in certain areas than in others. In specific parts of the province confusion in regard to divisional lines seems to have arisen, due to misinterpretations of a palæontological nature, while in other parts the confusion seems to be due to lithological similarities. The points involved are, on the whole, minor ones, and, perhaps, are not worthy of any very elaborate discussion. Nevertheless, stratigraphical geology is, at its best, complex, and therefore should receive every additional contribution which will tend to relieve its comlexity.

The Colorado formation has not been studied as thoroughly and systematically as is desired, yet a study has been made of a sufficiently large number of areas to warrant the establishment of more general division lines. The areas of the central-interior province which have been studied somewhat in detail are: The southeastern Colorado area, the Black Hills area, the eastern Dakota area, the Iowa-Nebraska area, and the Kansas area. Since I am more familiar with the detailed stratigraphy and palæontology of the last-named area I will discuss it and use it as a standard by which to correlate the other areas.

In the Kansan area two principal groups have been recognized for the Benton series. These groups are, the lower or Limestone group and the upper or Shale group. The division is based primarily on lithological grounds as the names indicate. The Limestone group admits of five subdivisions, such divisions

being made on either palæontological, lithological or economic conditions. The subdivisions are: The Bituminous Shale, the Lincoln Marble, the Flagstone Beds, the Fencepost Beds, and the Inoceramus Beds. The Shale group has two divisions, the Ostrea Shales and the Blue Hill Shales. The Niobrara series is divided into the Fort Hayes Limestone and the Pteranodon group, the latter being further divided into the Rudistes Beds and the Hesperonis Beds.

FORT BENTON

The bituminous shale.—Although I have named these beds as one of the subdivisions of the Limestone group I prefer to discuss them separately for convenience of correlation. The Bituminous shale is a moderately compact argillaceous shale which in some localities is somewhat calcareous. The prevailing color of the shales at the base of the beds is dark blue, which passes to light gray at the upper limit. The beds contain the remains of a marine fauna, since plesiosaurs' bones, sharks' teeth, and impressions of Inoceramus are found in them. The maximum thickness of the stratum is not more than twenty-five or thirty feet.

In the Arkansas valley in Colorado its stratigraphical equivalent, the Graneros shales,[1] reach a thickness of 200 feet. In the Huerfano area[2] these shales have a thickness of 100 feet. Near Sioux City, Iowa, and Ponca, Nebraska,[3] a bed of shales, having a thickness of forty feet, occupies the same geological horizon and possesses primarily the same characteristics. In the Black Hills area near Buffalo Gap these shales have a thickness of more than twice that of the Eastern area, being in the neighborhood of 100 feet in thickness. The stratum appears to be very persistent, occurring in all the known areas of the cen-

[1] GILBERT, G. K., The Underground Waters of the Arkansas Valley in Eastern Colorado, Seventeenth Ann. Rept. U. S. Geol. Surv., 1896.

[2] STANTON, The Colorado formation and its Invertebrate Fauna, Bull. U. S. Geol. Surv., 1893.

[3] CALVIN, The Relation of the Cretaceous Deposits of Iowa to the Subdivisions of the Cretaceous proposed by Meek and Hayden, Am. Geologist, Vol. XI.

tral-interior province. And although it varies much in thickness its faunal and lithological characteristics are remarkably uni form.

The Limestone group.—The Limestone group is recognized in all the areas except the Iowa-Nebraska and Eastern Dakota areas. Subdivisions have not been designated for the group in any of the areas except the Kansan. Although the subdivisions are persistent the divisional lines are arbitrary for the beds grade into each other. The Lincoln Marble is more easily differentiated on both palæontological and lithological grounds. It has a remarkably interesting and unique fauna. In the shallow marine waters where its beds were deposited, foraminifera, corals, and oysters were associated with sharks, fish, turtles, and saurians. The rock is composed almost wholly of foraminiferal remains, in which are imbedded sharks' teeth, fish teeth, shells, and other animal remains. So abundant are the teeth in certain portions of the rock that it gives a reddish hue to the surface on which they have been rendered visible by weathering.

The beds are composed of thin layers of a compact close-textured limestone, having an average thickness of three or four inches, and susceptible of moderate polish. On account of the last-named characteristic it is called, locally, marble. The limestone layers are separated by thin beds of shale of about the same thickness. The assumption that these beds are of shallow water origin is based on the presence of quantities of carbonaceous matter in the limestone and the highly carbonaceous character of the intercalated shale beds. Numerous fragments of fossilized trees and charcoal have been discovered in the beds in the Kansan area.

The Lincoln marble is notably persistent in the Kansan area. The same is true of the Black Hills area. In the latter area the layers of limestone are somewhat arenaceous, but the faunal characters are similar, as fish teeth and saurian bones have been noticed. It is presumable that when a careful study is made of the Benton stratigraphy in other parts of the province that the Lincoln marble will be differentiated. Such is not so likely to

be true in the case of the other subdivisions of the Limestone group, since the criteria are not so pronounced.

In the Iowa-Nebraska area, according to descriptions given of that region, the Benton limestone group seems to be entirely wanting. This may be due to a misunderstanding in regard to the proper position of the division line between the Benton and the Niobrara. The following is a description of the Benton in that region.[1] "Shales are more or less unctuous to the feel, somewhat variable in color and texture, containing remains of saurians and teleost fishes, the upper beds sometimes bearing impressions of *Inoceramus problematicus;*" while the Niobrara which rests upon the above described Benton shales is described as follows: "Calcareous beds consisting of chalk and thin bedded limestones, containing shells of *Inoceramus problematicus*, *Ostrea congesta*, and teeth of *Odotus*, *Ptychodus*, and other selachians; thickness, thirty feet."

It is not improbable that a part of these thirty feet of so-called Niobrara should be assigned to the Benton, since, in speaking further of the beds, the author says: "These (beds) consist in part of soft chalky material and in part of fissile limestone that divides under the hammer or on exposure to the weather, into relatively thin laminæ crowded with detached valves of *Inoceramus problematicus.*"

The above describes exactly the Inoceramus beds of the Benton in the Kansan area. In that area *Inoceramus labiatus*, syn. *problematicus*, makes its appearance in the upper Bituminous shale beds, and continues to increase in numbers until the Inoceramus beds are reached, where it attains the acme of its abundance. It then declines in numbers to the Blue Hill shale horizon, where it disappears altogether, and if it reappears at all in the Niobrara it is very rare.

The geological range of the species is confined to the lower Benton, and although its zone appears to be narrow its geological distribution is exceedingly wide, as it is reported from nearly all known Cretaceous areas. Mr. Gilbert[2] mentions it as the

[1] CALVIN, loc. cit. [2] Loc. cit.

characteristic fossil of the Benton limestone in the eastern Colorado area, and also speaks of its abundance in certain layers. *Inoceramus labiatus* has been confused in certain areas with *I. deformis* and other species of the same genus. This confusion has arisen on account of its reported association with *Ostrea congesta*. *Ostrea congesta* occurs in the Benton, where it is found adhering to a large nearly flat *Inoceramus*, but is never found adhering to the much smaller species, *Inoceramus labiatus*. In fact, it is rarely found associated with that species. *Ostrea congesta* occurs also in the Niobrara. It is here found attached to *Inoceramus pennatus, I. concentricus, I. platinus, Radiolites maximus* and other large shells. *Inoceramus sp.*, to which the ostreæ of the Benton are attached, resemble *Inoceramus platinus* of the Niobrara, but on account of the extreme brittleness of the Benton shell, due to its transversely fibrous structure, whole specimens cannot be obtained for examination.

But there is a distinction between the forms of the adhering ostreæ. *Ostrea congesta*, var. *Bentonensis* is a small thin subtriangular shell which, if permitted to grow uninterrupted, is almost flat. The upper valves are so thin that they are rarely preserved. *Ostrea congesta*, var. *Niobraraensis* is a larger, thicker shell, with the lower valve more capacious, and possessing near the hinge area well-marked vertical lines of muscular attachment. The upper valve is also thick, and in many specimens possesses adhering forms of the same species. The differences may not be marked enough to be considered specific differences, but they are sufficiently well developed to distinguish the two forms. It is well to bear in mind then that there is a species of *Inoceramus* in the Benton which possesses adhering forms of ostreæ, and that there is a similar species in the Niobrara possessing them, and that therefore *Ostrea congesta* adhering to *Inoceramus* cannot be taken as a criterion for either group unless the ostreæ are properly differentiated.

The shale group.—Resting upon the limestone group is a bed of shales called the Ostrea shales on account of the abundance of that fossil in them. These shales are argillaceous, so much

so in places that they might with propriety be called clay, and are variable in color. The prevailing color is dark blue. Here and there in the shales are thin beds of limestone containing *Inoceramus labiatus* and species of cephalopods. *Ostrea congesta*, var. *Bentonensis* attached to *Inoceramus sp.*, is the most abundant species. Fish teeth, sharks' teeth, and pavement plates and fossil wood containing species of *Parapholæ*, also occur. Near the upper limit the shales contain a species of *Inoceramus* with *Serpula plana* attached. The thickness of the Ostrea shales in the Kansan area is 150 feet. They are the stratigraphical equivalent of the lower Carlile shales in the eastern Colorado area. The Black Hill area possesses a bed of shales twenty or thirty feet in thickness, which is stratigraphically and palæontologically equivalent to the Ostrea shales. Specimens of *Serpula plana* and *Inoceramus labiatus* were found in an outcrop of the shales on Hat Creek, a southern branch of the Cheyenne River. The Ostrea shales in this area are somewhat arenaceous, and the prevailing colors are blue and light yellow. The Ostrea shales are wanting in the Iowa-Nebraska and eastern Dakota areas.

The Blue Hill shales.—The Blue Hill shales form the upper zone of the shale group. They are dark or slaty colored shales which, under the influence of weathering, break up into very fine, chaff-like fragments which are so light as to be moved about somewhat easily by the wind. On account of their fine, laminated appearance the shales are sometimes called paper shales. They are unfossiliferous and homogenous, except in the upper third. This zone has numerous argillaceo-calcareous concretions called septaria imbedded in its shales. Some of these concretions possess the cone-in-cone structure, while others are formed of concentric layers. Fissures in others of the concretions have been filled in by sedimentation with calcite which ranges in color from white to claret. These are the true septaria. Many of the concretions are highly fossiliferous. The following species have been collected from them: *Scaphites larvæformis*, *S. vermiformis*, *S. warreni*, *S. ventricosus*, *S. mullananus*, *Rostellites willistonii*, *Pri-*

onocyclus Wyomingensis, Placenticeras placenta, Inoceramus undabundus and *I. tenuirostratus.*

In the Kansan area the Blue Hill shales have a thickness of 100 feet. The upper Carlile shales form their stratigraphical equivalent in the Colorado area. The septaria zone occurs in relatively the same position in the Carlile shales, and presents approximately the same lithological characteristics. The total thickness of the Carlile shales is from 175 to 200 feet, including the upper and lower beds, the equivalents of the Blue Hill and Ostrea beds. In the Black Hills area a bed of shales thirty to forty feet in thickness, bearing calcareous concretions of the cone-in-cone structure is the stratigraphical equivalent of the Blue Hill shales. The Blue Hill shales as well as the Ostrea shales have no equivalent in the Iowa-Nebraska and eastern Dakota areas.

THE NIOBRARA

The division line between the Benton and the Niobrara in the Kansan area at least is not an arbitrary one. Lithologically it marks a change from dark argillaceous shale to comparatively pure chalk of remarkable whiteness, scarcely compact enough to deserve the name limestone. The change is one of abruptness, there is no transition zone. The shale does not appear again. A massive stratum of limestone rests upon the dark shales, and there is no intermediate layer, part chalk and part shale. Palæontologically the change is marked by the ushering in of an almost entirely new fauna.

Two principal divisions of the Niobrara are recognized in the Kansan area. These are the lower or Fort Hays limestone and the upper or Pteranodon beds. The division may be said to rest on both lithological and palæontological grounds. The Pteranodon beds are further subdivided into the Rudistes and Hesperonis beds. This division is made on purely palæontological evidences.

The Fort Hays limestone.—The Fort Hays limestone is in massive layers of from two to four feet in thickness, and the

total thickness of the bed is fifty to sixty feet. When taken from the quarry it is very soft and easily cut and carved into any desired shape. It hardens somewhat on exposure. The lower portion, except for the minute cocoliths and foraminiferæ is largely unfossiliferous. The upper portion contains many species of invertebrates.

In the Colorado area the lower fifty feet of the Timpas beds is the equivalent of the Fort Hays. The zone is described as being composed of layers of a compact, rather fine-grained limestone of a light gray color which becomes creamy white on weathered surfaces. The layers are from a few inches to three feet in thickness, and are separated by thin beds of shale usually one or two inches thick.[1]

In the Black Hills area the position of the Fort Hays is occupied by a bed of shales containing a layer of limestone two feet in thickness. In the Iowa-Nebraska area it seems probable that the Fort Hays beds rest upon the Benton limestone, but the line of separation may be difficult to establish. In the eastern Dakota area the equivalent stratum reaches a thickness of 130 feet.

The Pteranodon beds.—The upper division of the Niobrara comprises the true chalk of the Kansan area. The chalk varies in color from a light blue through lavender, yellow, and buff, to red and orange. Under fresh exposure it presents the appearance of a blue shale, and has often been taken for such. The freshly exposed beds, however, under the weathering influence of air and water, soon change their shale-like appearance and blue color. The change in color is probably due to a chemical change in the iron compounds in the chalk. Chert beds occur in some places interstratified with the chalk. These are only of very local occurrence, however. The chalk is used to some extent as a mineral pigment in the manufacture of paint. Fossil wood is not of rare occurrence in the chalk, and it is frequently found pierced with the shells of *Parapholæ*. Fragments of amber[2]

[1] GILBERT, loc. cit.

[2] WILLISTON, The Niobrara. Kan. Univ. Geol. Surv., Vol. II.

have been obtained from some of the specimens of fossil wood. Charcoal also occurs in the chalk as well as in the Benton limestone. Nodules of pyrite are abundant in some outcrops.

The lower Rudistes beds present a varied and extensive invertebrate fauna. The Hesperonis beds contain fewer invertebrates, but a vastly greater number of vertebrates than the lower Rudistes beds.

The upper 125 feet of the Timpas beds is probably the equivalent of the Rudistes beds, while the Apishapa beds are the equivalent of the Hesperonis beds in the Colorado area. In the Black Hills area the position of the Pteranodon beds is occupied by a bed of shales with a thin bed of limestone. The beds are wanting in the Iowa-Nebraska and eastern Dakota areas. In the following table, which is intended to show the relation of the different subdivisions in the representative areas, the eastern Dakota area is omitted, as it does not differ materially from the Iowa-Nebraska.

		Kansas area	Colorado area	Black Hills area	Iowa-Nebraska area
THE COLORADO FORMATION	NIOBRARA SERIES	Pteranodon beds, 275′: Hesperonis beds, 150′	Apishapa beds, 200′	Shale, limestone, 150′	Wanting
		Pteranodon beds, 275′: Rudistes beds, 125′	Upper Timpas, 125′	Shale, limestone, 200′	Wanting
		Fort Hays limestone, 50′ to 60′	Lower Timpas, 50′	Limestone, 2′ to 4′	Chalk, limestone, 40′
	BENTON SERIES	Shale group, 250′: Blue Hill shales, 100′	Carlile shale, 200′: Upper Carlile	Shale, 30′ to 40′	Wanting
		Shale group, 250′: Ostrea shales, 150′	Carlile shale, 200′: Lower Carlile	Shale, 20′ to 30′	Wanting
		Limestone group, 40′ to 50′	Greenhorn limestone, 25′ to 40′	Limestone, 10′ to 15′	Wanting (?)
		Bituminous shale, 20′ to 40′	Graneros shale, 200′	Shales, 100′	Shales, 40′

W. N. LOGAN.

EDITORIAL

THE December number of the *Astrophysical Journal* gives a translation of a paper "On the Constitution of Gaseous Celestial Bodies," by A. Ritter, which possesses much geological significance if its general conclusions are trustworthy. The original paper is one of a series of eighteen which appeared between the years 1878 and 1883 in Wiedemann's *Annalen*, but its astronomical and geological bearings appear to have escaped the attention they merit, and for this reason it is now reproduced. Ritter attempts to compute the time which would be occupied by a gaseous solar sphere of the dimensions of the earth's orbit in contracting to the dimensions of the present sun; in other words, the time of evolution of the solar system from the separation of the earth to the present stage under the Laplacean hypothesis, with certain qualifications. The computation is necessarily based on certain assumptions, some of which require modification in the light of more recent investigations, but any competent attempt at a mathematical discussion of the rate of solar evolution under the gaseous hypothesis constitutes a notable contribution to the cosmical phases of geology. The conclusion is reached that about 5,500,000 years ago the solar radius was equal to the radius of the earth's orbit. On the assumption that the effective radiating disk of the sphere was always equal to the whole disk, Ritter concludes that the solar mass shrank from dimensions of the earth's orbit to a dimension ten times the present sun's diameter in the remarkably short period of 255,710 years. On the assumption that the effective radiating disk was half of the whole disk, he finds that a similar shrinkage would take 511,420 years. In the latter case the total time occupied by the solar mass in contracting from the earth's orbit to its present dimensions would be about 5,765,000 years. This con-

clusion is based on the assumption that the thermal capacity was 1.41. On the assumption that it was five thirds, which is the largest permitted by the mechanical theory of heat, the conclusion is reached that the contraction could at most have occupied about 6,500,000 years.

The foregoing computations are based upon Pouillet's estimate of the present radiation of the sun. If the computation be based on recent estimates, which give a rate at least 50 per cent. greater, the resulting time is about 4,336,000 years. Ritter recognizes that the departure of the body from a spherical shape arising from rotation would modify the results, as these were based on the assumption of a spherical form throughout the whole period, but as this departure was large only during the comparatively small portion of the whole interval occupied in the contraction from the earth's orbit to twice the sun's present diameter, the correction is limited, but yet may be considerable. In view of this the author remarks: "For these reasons we cannot give the maximum value $t=4{,}336{,}000$ years found above the significance of a superior limit for the age of the earth, the less in fact since the original assumptions must still be regarded as hypotheses imperfectly satisfied. Nevertheless it seems permissible to conclude from the above investigation that the actual age of the earth must be far less than the estimates of some geologists, who place it at hundreds of millions of years."

Whatever corrections may be applicable to such a computation, the attempt to subject the time factor of the gaseous hypothesis of the evolution of the solar system to rigorous mathematical inquiry is a most helpful one. The discussions of Lord Kelvin and others who have attempted to assign limits to the age of the earth by merely determining the maximum amount of heat which the sun can have radiated in the past, on the gravitational hypothesis, do not really get home to the question, since they do not determine the rate of radiation of heat in the past. If that rate were faster than the present rate it is obvious that the time would be correspondingly shortened; if

slower, it would be correspondingly lengthened. This radical defect is obviated, in the main, by Ritter's method.

If the period occupied by the supposed gaseous ancestor of the sun in shrinking from the earth's orbit to its present size is such as computed by Ritter, or if it be any period of that order of magnitude, it will probably be the conclusion of geologists and biologists that the hypothesis of such a gaseous sun is irreconcilable with geological evidence and with the phenomena of biological evolution. At any rate, this is a mode of testing the validity of the gaseous hypothesis which merits the careful consideration of those competent to pass judgment upon it, and it is earnestly to be hoped that the method of Ritter and his assumptions will be subjected to critical reëxamination in the light of the most recent researches.

The press announce that in a recent lecture before the Lowell Institute, Dr. See stated certain radical conclusions which he has reached with reference to the temperatures of the exteriors of gaseous bodies. We understand that his fundamental formula is closely analogous to one of those derived by Ritter. Applied to the sun when expanded to the dimensions of the earth's orbit, it gives a relatively low external temperature. It is not clear that this low outer temperature is compatible with the rapid loss of heat that appears to be involved necessarily in Ritter's rapid evolution, and we do not understand that Dr. See holds the latter view. Geologists will watch with interest the appearance of Dr. See's new views in authentic form, and may well congratulate themselves on the prospect of a discussion of the nebular hypothesis on new lines.

T. C. C

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THE eleventh annual meeting of the Geological Society of America, which was held at Columbia University, in New York City, was characterized by a large attendance of the Fellows and by a very general interest in the proceedings. The accommodations furnished by the University were sumptuous in many ways the elegant Schermerhorn building proving highly satisfactory

except for the acoustic properties of the large lecture hall. The opportunities for luncheon were adequate and agreeable. The social features of the meeting, consisting of receptions at the American Museum of Natural History and at Professor Osborn's residence, and the annual dinner, were eminently successful. The dinner was pronounced the most satisfactory yet enjoyed by the society.

The program was varied and attractive, no one branch of the subject being greatly in excess of others. General geology, stratigraphy, physiography, glacial geology, palæontologic geology, and petrology were each represented by able exponents. But to those who attempted to follow the programs, it was evident that the shortness of the time devoted to the meetings, together with the length of the program of a well attended session, necessitate a better regulation of the proceedings than it has heretofore been the custom of the presiding officers to enforce. The evident hesitation on their part to interfere with the presentation of papers by Fellows of the society, while agreeable to the individual at the time, is not conducive to the best interests of the society as a whole, that is to say, to the other Fellows in general. Interference may properly be exercised in the case of those who exceed the time allotted them for the presentation of papers, especially since in most instances the time is that determined by themselves.

There should also be some rule limiting debate both as to length and matter. The exhibition of lantern views is a most valuable aid to the presentation of many subjects, which was very well shown at the meeting just held, but the selection of illustrations should be limited to those which actually illustrate the subject, and should be made to avoid unnecessary repetition.

The result of these abuses, the overrunning of time in presentation and discussion, and the introduction of unnecessary illustrations, is the crowding of papers on the last day of the meeting, the consequent haste in their delivery or the curtailing of considerable parts of them, and a general sense of dissatisfaction; first, with those who said too much, and last, with those

who said too little. The correction of these evils should rest with the presiding officers, but must originate with the Fellows themselves. It is to be hoped that some regulations will be formulated and put into operation at the next winter meeting in Washington, D. C.

J. P. I.

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In an article on igneous intrusions in the October-November number of this Journal, Professor Iddings states that, "Russell has called attention to what he considers volcanic plugs in the region of the Black Hills of South Dakota." I desire to deny the statement that the intrusions referred to were called *volcanic* plugs; abundant evidence was, I think, presented to show that they are, as I termed them, *plutonic* plugs. They are intrusions of igneous magmas forced upwards into horizontally stratified rocks so as to raise domes above them; but did not reach the surface, and hence should not be considered as occupying the conduits of volcanoes, and so far as can be judged, did not expand laterally after the manner of laccoliths. Not only one such intrusion was described, but several in various stages of exposure by erosion, from an unbroken dome of stratified beds, presumably with an intruded plug beneath, represented by Little Sun Dance Hill, to the imposing fluted column of Mato Tepee, over 600 feet high. Associated with these plug-like intrusions are what appear to be true laccoliths, as Warren Peak, for example. When this instructive region is more thoroughly explored, we may expect to find a series of examples illustrating the transition from plug-like to cistern-like intrusions or laccoliths. For these reasons it is well to hold the locality referred to, as furnishing the type-group of plutonic plugs.

The evidence just referred to was stated in the article[1] criticised by Iddings, but without having seen the intrusions and without presenting any new observations concerning them, he brushes it aside and restates the same kind of evidence for the

[1] Igneous intrusions in the neighborhood of the Black Hills of Dakota, Jour. Geol., Vol. IV, 1896, pp. 23–43.

apparent purpose of introducing a high-sounding Greek name in place of the term used by me.

In discarding the evidence of the plug-like character of the intrusions near the Black Hills, Iddings states that it is probable they are central remnants of small laccoliths, for the reason that the prismatic columns of which they are largely composed are vertical, "whereas they should be horizontal in the body of a volcanic plug." Unfortunately for this dictum, the prisms in many true volcanic plugs or necks, like those about Mt. Taylor, New Mexico, described by Dutton, are vertical.

In the same spirit in which Iddings discards the evidence of the plug-like form of the intrusions under consideration, and with equal justice, one might use his own language in reference to the account he himself gives of Mt. Holmes, the new type-example brought forward and of the accompanying, largely ideal diagram; "He has mentioned nothing that demonstrates or even indicates that it possesses the character of a plug;" it might just as well be a laccolith eroded down to the feeding conduit.

The term *bysmalith* which Iddings seeks to substitute for plutonic plug, means simply plug-stone, and may be used with equal propriety for both volcanic and plutonic intrusions, of plug-like form; if one wishes to make this convenient distinction the terms *volcanic bysmalith* and *plutonic bysmalith* would have to be used. I fail to see any advantage in such a clumsy nomenclature. The word bysmalith is so similar to *bathylith*, already in the field and also used by Iddings in the article referred to, that confusion must arise if this rechristening is permitted. It seems to me that American geologists should use their mother tongue whenever it can be made to serve, and usually it will be found rich enough to express all the ideas they may have, instead of searching the dictionaries of the dead languages for more or less accurate translations of plain English terms.

ISRAEL C. RUSSELL.

[The use of the term volcanic instead of plutonic in referring to the intrusions in question was inadvertent; much of the assumed distinction in the use

of the terms being artificial and misleading, the writer has become indifferent in his use of both terms.

Nevertheless, with regard to what Professor Russell has called plutonic plugs in the Black Hills region, it may still be said that "In his description of them he has mentioned nothing that demonstrates or even indicates that they possess the character of a plug. In each case they may be central remnants of small laccoliths."

The question, whether the evidence regarding the nature of the Holmes bysmalith is of the same kind as that offered for the character of the Black Hills intrusions, may very well be referred to our fellow-geologist. J. P. I.]

Reviews.

Fossil Medusæ. By C. D. Walcott. Monog. U. S. Geol. Survey, Vol. XXX, pp. 1–201, Plates I–XLVII, Washington, 1898.

This monograph of the fossil medusæ of the world, is the outcome of a careful study of some 9000 specimens of these organisms from the Middle Cambrian shales of the Coosa valley, Alabama. It was the author's first intention to include his observations upon these fossils in a work upon the Middle Cambrian fauna, but as the fossil medusæ from other geologic horizons and from other parts of the world became involved in the investigation, the present monograph was prepared.

Notwithstanding the evanescent character of these jelly-like organisms, their fossil remains have been preserved in the Lower Cambrian strata of New York and several European localities, in the Middle Cambrian of Alabama, in the Permian of Saxony, and the Jurassic of Bavaria. The Alabama specimens occur as more or less radiately lobed, semi-cherty nodules which weather out from the shales in great numbers.

A new family, *Brooksellidæ*, is founded for the reception of the genera *Brooksella* and *Laotira* from Alabama and *Dactyloidites*, previously described from the Lower Cambrian of New York. Two species of *Brooksella* and one of *Laotira* are described, and the one species of *Dactyloidites* is redescribed, and it is surprising that the details of structure of these ancient "jelly-fish" can be so fully determined. The generic term *Medusina* is used for the designation of all those fossil Medusæ whose true generic relations cannot be fully determined, and in this group are placed the three Cambrian species from Sweden. Some observations are made upon the genus *Eophyton* in which have been placed various trails which may have been produced by the tentacles of floating medusæ dragging upon the mud of the sea bottom, or by floating seaweeds. The remaining pages of the volume are devoted to the descriptions of the European Permian and Jurassic forms.

Stuart Weller.

The University Geological Survey of Kansas. Vol. IV. Paleontology. Part I. Upper Cretaceous. SAMUEL W. WILLISTON, Paleontologist. Topeka, 1898.

It is with much interest that we examine this work on the paleontology of Kansas. Professor Williston and his associates have made a successful effort to produce a work of popular as well as scientific value. The effort is worthy of commendation. The manner in which the subjects are presented cannot fail to make the book useful in many places where a purely scientific work would be of little value.

Professor Williston reviews the work on Birds, Dinosaurs, and Crocodiles; but the most interesting and instructive part of his work is the monograph on the Mosasaurs. While his work is primarily with the Kansas Mosasaurs, he does not confine his study to these, but briefly and concisely covers the whole subject. Here, especially, he has been successful in keeping the interest alive.

The monograph opens with a brief historical summary of the Mosasaurs — their discovery and the publications concerning them. This is followed by their range, distribution, and classification. He refers to the controversies over the relations of these reptiles, and arrives at the conclusion from his own study, that they are entitled to be classed as "an independent group among the *Lacertilia*." In this connection he quotes the classification proposed by Dr. Baur. The greater part of the monograph is devoted to a careful anatomical comparison and description of these interesting reptiles, many of which the author originally discovered and described. No pains have been spared to make the work complete and useful.

In his systematic descriptions Professor Williston points out a number of facts of popular, as well as scientific interest. The Mosasaurs are described as "varying in length between five and forty feet," a decided reduction in size from the Mosasaurs of the text-books, which are given a maximum length of 100 feet. Another fact which seems to have escaped the notice of former collectors is the deformation of the bones undergone in the process of fossilization, especially in the Niobrara formation. The bones have yielded as if made of plastic material. The deformation has furnished the characters upon which many new species have been based. The author concludes that this will cut out about four fifths of the species that have hitherto been described.

The turtles are described by Professor Williston and Professor E. C. Case, and the microscopic organisms by C. E. McClung.

Mr. W. N. Logan who has done much toward giving us a clear conception of the stratigraphic relations of the Upper Cretaceous, presents an excellent discussion of the invertebrates of the Benton, Niobrara, and Fort Pierre groups. He not only reviews the species hitherto described, but adds the descriptions of many new ones which he has found. His work is admirably arranged, and the species so tabulated, that the whole forms a convenient paper of reference. It is to be hoped that much more work of this kind may soon be done in the great Interior Cretaceous region, that a more definite knowledge of its rich invertebrate fauna may be available.

W. T. Lee.

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— Ami, Henry M. Note on the Physiography and Geology of King's County, Nova Scotia. From the Ottawa Naturalist, Vol. XII, Nos. 7 and 8, November 1898. Ottawa, Canada.

— Annual Progress Report of the Geological Survey of Western Australia, for the year 1897. A. G. Maitland, Geologist, Perth, Australia. With map showing position of Artesian bores in vicinity of Perth; and other geological maps.

— Callaway, Dr. C. On the Metamorphism of a Series of Grits and Shales in Northern Anglesey. From the Quarterly Journal of the Geological Society for August 1898. London, England.

— Dall, William H. A Table of the North American Tertiary Horizons, correlated with one another and with those of Western Europe, with Annotations. Extract from the Eighteenth Annual Report of the U. S. Geological Survey, 1896–7. Washington, 1898.

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